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Heating and Cooling Technology and Global Solutions for Food Distribution

Fuji Electric

Innovating Energy Technology

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Heating and Cooling Technology and Global Solutions for Food Distribution

In the field of food distribution, there has been an increasing demand for vending machines with enhanced energy saving, transportation and storage equipment for delivering food safely and securely, store related equipment, and solutions that combine these machines and equipment with IT. Fuji Electric has been responding to these demands through its research and development efforts in related technologies based on the concepts of "high quality," "diversification," "environment" and "globalization" in order to expand into markets with products that meet the exact needs of its customers.

In this issue of FUJI ELECTRIC REVIEW, we will introduce heating and cooling technology, which is indispensable for energy saving, products that utilize this technology, and unique products for the global market, as well as element technologies, such as product vending mechanisms and currency identification.

Cover Photo (clockwise from the right side):
Glass front vending machine "Twistar," Cold storage container "Chilled Type D-BOX," Product dispensing mechanism for vending machines for global market

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Preface

Expectation of Development in Food Distribution Technology

OGOSHI, Hiro*

There is a range of temperatures at which each food is most delicious. The range is said to be ±25 °C to 30 °C around human body temperature although it varies depending on the food. As a researcher of technologies related to the cooking and processing of food products and the preparing of delicious food, my primary interest is in how to keep the taste of food during the distribution process. Equipment to maintain a constant temperature is thought to be crucial in keeping food products delicious and safe for consumers. I have high expectations for the development of food distribution technologies, while at the same time focusing on methods and distribution equipment used to keep the taste of food.

Looking at food culture, it was common long ago for families to prepare and eat meals at home, i.e. "home-cooking." However, food custom has recently tended to move outside the home, with more opportunities for families to eat at restaurants. In other words, more and more food is being prepared and eaten outside the home, that is, "eating out." On the other hand, with changes to food custom caused by the appearance of convenience stores in 1974 and other subsequent changes such as the increasing women's social advancement, more families are purchasing side dishes at department stores and other locations, setting them up on their tables for meals, i.e. "prepared foods." Although supermarkets play a large role in making food ingredients available to consumers for home cooking, these same supermarkets also sell side dishes, supporting prepared foods. For this reason, supermarkets have been provided with refrigerated and frozen showcases in response to the demands of various consumers. Twenty-four-hour convenience stores also offer a wide variety of prepared food products so that customers can purchase just the amount they need to eat. For example, products such as boxed lunch meals are stored at a low temperature to keep them fresh longer and are warmed up at the register when purchased. Convenience stores have offered an expanding range of services over the past few years, and even sell warm products during the winter season. The ideal temperature to enjoy warm food is around 65 °C, and offering products at such temperature should increase earnings. Foods such as salad and vinegared dishes are most delicious at low temperatures (from 5 °C to 10 °C), stores therefore keep such foods within this range and mark their expiration date on the package. In this way, more products will continue to be sold at a variety of temperatures, even in the prepared food industry.

In this issue, I first focus on technological research related to chilled transport containers. Cold storage containers used for transportation in food distribution are capable of simultaneously transporting food products with different temperature ranges. Transporting food products at their ideal temperature is also excellent when it comes to keeping the taste of food. This technology can be used in transporting other products that require cooling such as medical products and can be applied to a wide variety of situations.

My second focus point is the introduction of an energy-saving control system that was developed for use in supermarket distribution centers as an example of technology related to food distribution. Energy-saving control systems for freezing-refrigerating warehouse have been customized for warehouse use. These systems include control elements for mechanisms used in each warehouse, such as unit coolers. According to food manufacturers affected by the Great East Japan Earthquake, distribution has stagnated and suffered more damage due to reduced food distribution warehouse functionality including power outages. It would be most beneficial if measures during power outages could also be investigated.

The remarkable third focus point is research related to vending machines. Vending machines are the food distribution devices that we encounter most often in train stations and on the street in our daily lives. In terms of locations where products are sold, nothing is more convenient. Although we can expect much of technologies to serve cold soft drinks and warm coffee or tea, and even with the convenience they offer, there are concerns over power consumption. In our social circumstances which demand technologies that are friendly to the environment, we expect improved energy saving and convenience.

This sums up the three points I focused on in this issue. I hope that technologies to save energy and distribute food at low temperatures from the fundamental perspective of food safety will continue to make progress, and I am looking forward to the development of equipment that will be able to keep the taste of food.

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Heating and Cooling Technology and Global Solutions for Food Distribution: Current Status and Future Outlook

SUGIMOTO, Koji*

1. Introduction

Food distribution needs are changing in Japan due to depopulation, the decreasing birthrate and aging population, increasing numbers of single households and women's participation in society. High quality products and services are needed that can meet these diversified individual needs.

Furthermore, there are increasing expectations for the development of new food distribution solutions such as vending machines overseas, following lifestyles changes especially in Asia regions.

Fuji Electric's Food Distribution Division is working to research and develop related technologies with 4 keywords in mind in order to meet these needs: "high quality," "diversification," "environment" and "global support." This paper describes these new technologies.

2. Support for High Quality and Diversification

2.1 Ultra-compact cup-type vending machine

Consumers require high quality at any locations that are close to them, such as workplaces or at home.

In order to respond to demand for high quality, freshly-made coffee at offices, Fuji Electric has developed a new cup-type vending machine that is easy to install in offices, compact and higher maintainability (see Fig. 1). The new slim machine is designed in pursuit of rich and delicious coffee. It uses a regular coffee extraction system that is a core technology in traditional cup-type vending machines and a compact cup mixing system (refer to "Office-Use Ultra-Compact Cup-Type Vending Machine 'FJX10'" on page 168).

2.2 New fixtures in convenience stores

In the convenience store industry, in addition to the traditional convenience, new high quality products are being created constantly in respond to the needs of consumers. This requires equipment development that is flexible and suits a variety of needs, such as the development of fixtures that satisfy the requirements listed below, and the development of new showcases that can hold more products.

(a) Equipment that suits new product shapes and characteristics must be provided
(b) Fixture operation must be simplified, and it must be possible for anyone to provide high quality services easily
(c) Equipment must be safe and secure from a food hygiene perspective

Fuji Electric has responded with rapid develop-

Fig.1 Ultra-compact cup-type vending machine "FJX10"

(a) Coffee machine (b) Donut fixture

Fig.2 Counter fixture

* Food & Beverage Distribution Business Group, Fuji Electric Co., Ltd.

ment in order to launch equipment in a timely manner in line with new customer product releases (see Fig. 2).

In addition to sharing issues with the Production Division and engaging in concurrent development, this requires element technology development that captures market needs on a regular basis and that can quickly respond to demand, as typified by technologies to extract rich and aromatic coffee over a short period of time.

2.3 Support for high capacity and space saving

Fixtures used in convenience stores are required to contain many new products in a timely manner, with a limited amount of space. One example is the inverter refrigerator mounted drink showcase (see Fig. 3). This fixture offers more product display shelves, thus increasing display area while significantly reducing the amount of power consumption.

In reducing power consumption, we have developed proprietary airflow control technology for cooling within the housing and improved temperature distribution within the housing, making it possible to efficiently control temperatures with little energy.

We also analyzed the amount of power consumption and made several changes such as revising the heater that takes care of dew condensation, to eliminate energy loss as much as possible and achieve a 50% reduction in power consumption over previous models (refer to "Drink Showcase Equipped with Inverter Freezer" on page 178).

2.4 Support for multiple temperature range logistics

It is well known that transporting food at a constant temperature can retain the quality of said food. Foods are growing more diverse and the demand for higher quality products (good fresh products) is increasing. There is an increasing need for multiple temperature range logistics*1 in which many foods are transported at their ideal temperatures. To meet this need, we have developed the "D-BOX" cold roll box pallets for delivery. Transporting food with systems that use this container allows small units of food to be transported at a constant time and temperature from production areas to stores, without using refrigerated trucks (see Fig. 4). Furthermore, this technology allows for easier direct shipments of high quality foods from production areas to stores (refer to "Cold Storage Container 'Chilled Type D-BOX'" on page 172).

Fig.3 Inverter refrigerator mounted drink showcase

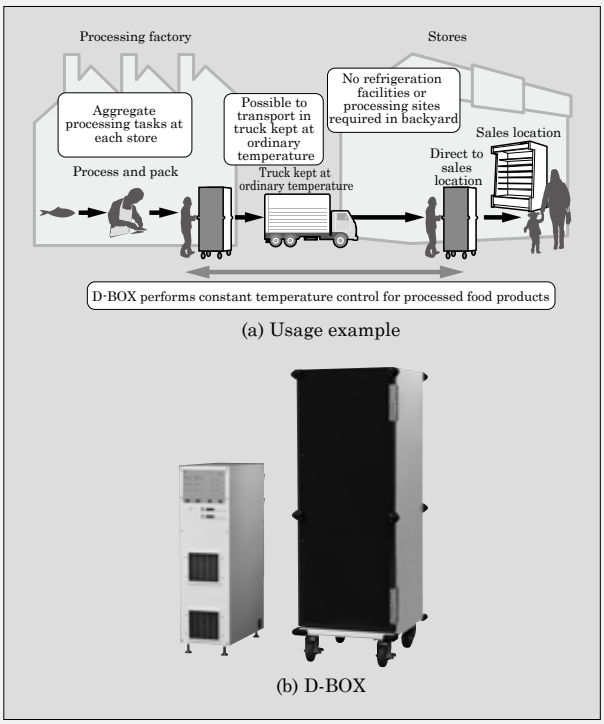

Fig.4 "D-BOX" usage example

3. Environmental Response and Energy Saving Technology

We have actively worked to reduce energy consumed by vending machines from an early stage, with the goal of preserving the global environment. Canned beverage vending machine power consumption in FY2015 fell to 17% compared with products for FY2001 (see Fig. 5). Roughly 80% of the energy consumed by vending machines is devoted to cooling and heating products (see Fig. 6).

Fuji Electric has been able to reduce power consumption through developing heat pumps, heat insulating, peak shift technology that reduces power

***1: Multiple temperature range logistics**
An optimal temperature range is required depending on each product for product distribution. This is referred to as multiple temperature range logistics, and includes all different temperature ranges, such as "frozen," "chilled" and "dry."

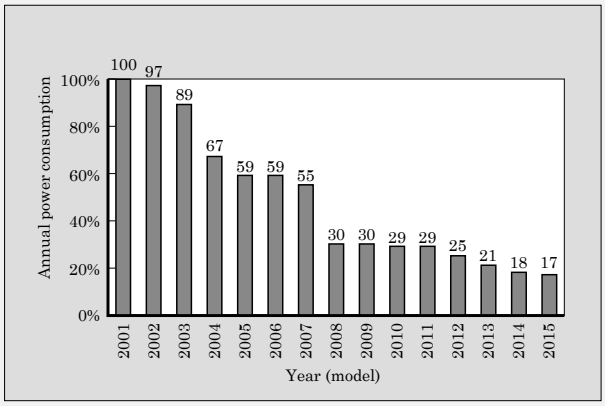

Fig.5 Power consumption trends in can and bottle beverage vending machines

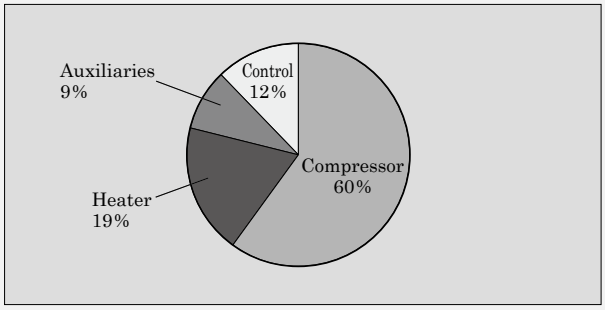

Fig.6 Electric energy distribution for canned beverage vending machine

consumption during the day, and other technologies.

3.1 Heat pump technology

Conventionally, exhaust heat generated through cooling products was thrown away outside the housing of the vending machine. Focusing on this exhaust heat, Fuji Electric was the first in the industry to release vending machines that use heat pump*2 technology. Instead of throwing exhaust heat away, this technology uses it to heat beverages. This heat pump system cools some products while warming others, and is unique to beverage vending machines (see Fig. 7). At least 90% of the canned beverage vending machines being shipped today make use of this technology.

In order to further reduce power consumption, we brought the following 2 technologies to market in FY2014:

(1) Ejector refrigerating cycle for CO_2 based heat pump type vending machines

We were the first to install ejectors*3, used in car air conditioners and water heaters, in vending machines that use natural CO_2 refrigerant*4 and brought vending machines with significantly improved efficiency and reduced (25%) power consumption to market.

Conventionally, refrigeration cycles that use CO_2 refrigerant work at a higher pressure than those that use hydrofluorocarbon refrigerant*5. This requires more power to drive the compressor, which reduces efficiency.

Meanwhile, the ejector refrigerating cycle takes advantage of the properties of CO_2 refrigerant. By adopting a pump action mechanism to suction evaporator refrigerant that utilizes expansion-loss energy, we have achieved a reduction in energy required for compression. Furthermore, as shown in Fig. 8, a gas-liquid separator was added after the expansion stroke to separate gas suctioned by the compressor

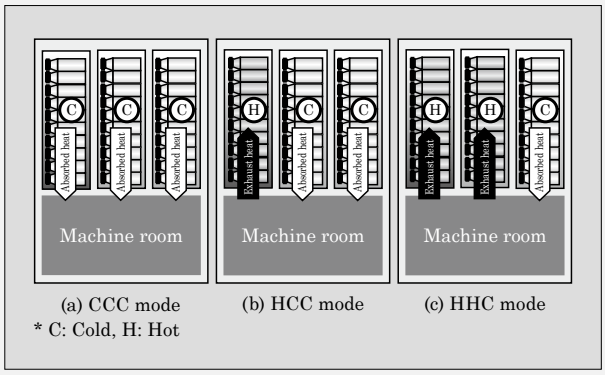

Fig.7 Heat pump heating structure

***2: Heat pump**

Heat pumps pump "heat" from low temperature parts to high temperature parts. This means that low temperature parts are even lower, while high temperature parts are even higher. This principle is also used in refrigerators and air conditioners. Refrigerant transfers heat between indoor and outdoor equipment, cooling and heating air. Heat pumps can transfer more heat than the workload of the compressor, and are drawing attention as one way to efficiently save energy. Fuji Electric vending machine heat pumps use both exhaust heat from cooling chambers and atmospheric heat in heating chambers. As switching the two heat sources as needed, the heat pumps are called "hybrid heat pumps."

***3: Ejector**

One kind of fluid pumps in which high-speed jets accelerated by nozzles draws in surrounding fluid, increasing pressure via a diffuser. They are also used for such applications as condensers in steam turbines and pumps in vacuum chucks. There are no moving parts, making them easy to maintain and usable even in clean environments. For details, refer to Supplemental explanation 1: "Ejector" on page 207.

***4: CO_2 refrigerant**

Refrigerant is a substance used in cooling to emit or absorb latent heat by changing phase from liquid to gas or gas to liquid. In contrast with conventional fluorocarbon refrigerant, CO_2 refrigerant is a natural refrigerant with an extremely small greenhouse effect that does not damage the ozone layer. It has a global warming potential of 1 (standard refrigerant when calculating potential) and an ozone depletion potential of 0.

***5: Hydrofluorocarbon refrigerant**

Hydrofluorocarbon refrigerant is an alternative chlorofluorocarbon. It is used as an alternative to specified chlorofluorocarbons (CFC). Alternative chlorofluorocarbons are refrigerants developed to curb damage to the ozone layer.

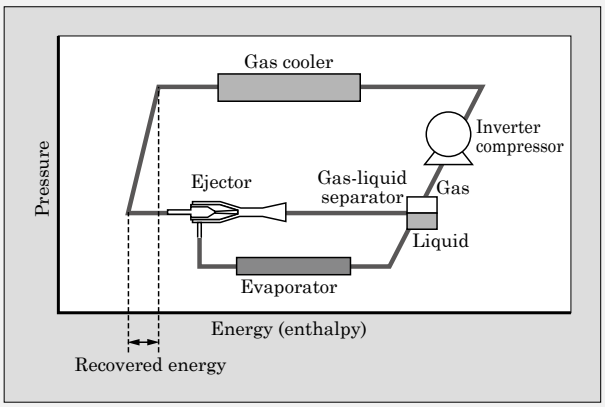

Fig.8 Ejector refrigerating cycle

and liquid refrigerant that flows to the evaporator, in order to improve refrigerator efficiency (refer to "Heat Pump Vending Machine Equipped with CO_2 Ejector Refrigerating Cycle" on page 158).

(2) ZERO heating power vending machine "Hybrid ZERO"

Fuji Electric has applied heat pump technology to develop a proprietary hybrid heat pump system that uses both exhaust heat generated when cooling products contained and outside air as heat sources. We have helped to significantly reduce the amount of power consumption by deploying this system throughout the market.

We have developed the ZERO heating power vending machine "Hybrid ZERO," which further advances heat pump technology and makes use a method that does not use the heater that was partially used depending on the season (mode), achieving a yearly power consumption that is 15% less than previous hybrid heat pump vending machines. The Hybrid ZERO heats all heating chambers using a heat pump, resulting in a significantly greater heating load fluctuation compared with previous models. Heating capability is improved by diverting heat generated from the compressor to the heat pump. To improve efficiency when less heating capability is required, we have adopted a highly efficient inverter compressor that can work at a slower speed than previous models, resulting in improved energy saving. (Refer to "ZERO Heating Power Vending Machine 'Hybrid ZERO'" on page 163.)

3.2 Heat insulating technologies

One important technological issue with vending machines is heat insulating technology to restrain heat transfer between the heating chamber and the cooling chamber. When products are cooled in one chamber while warmed in a neighboring chamber, insufficient heat insulation between the chambers will cause increased heat transfer. We have been developing technologies to restrain heat transfer through door components by thoroughly measuring vending machines to gain a complete understanding of the path heat travels when passing through parts connecting the door and housing.

In addition to these heat insulating technologies, we have developed functionality to significantly reduce power consumption throughout the day by storing heat evenly in products contained.

This functionality has been developed in response to recent circumstances of power supply. It can be used to store cool air at night, which is then utilized to make cool beverages available throughout the day, even when daytime cooling operation is stopped for a long time (peak shift technology).

3.3 Response to global warming (use of low GWP refrigerants)

With the enactment of the "Act on Rational Use and Proper Management of Fluorocarbons" (Fluorocarbons Emission Control Law) in April 2015, specific requirements to prevent global warming are now placed on the freezing-refrigerating equipment business operators.

This was originally a regulation on recovery and destruction during disposal, but now covers the use of refrigerants with a low global warming potential (GWP*6) and the management of fluorocarbons being used. This clearly defines the responsibilities placed on not only manufacturers, but also on freezing-refrigerating equipment business operators.

The main responsibilities are listed below. Regulations on business operators have been determined in some detail.

(1) Responsibilities concerning equipment installation
(2) Responsibilities concerning equipment utilization
  (a) Implementation of equipment inspections
  (b) Measures on leak prevention system and prohibition on filling unrepaired devices with refrigerant
  (c) Retention of inspection log
  (d) Calculation and reporting of estimated fluorocarbon leakage
(3) Responsibilities concerning equipment disposal

Fuji Electric has actively worked to use refrigerant with a low ozone depletion potential (ODP*7) and GWP, and to reduce the energy we use from an

***6: Global warming potential (GWP)**

GWP stands for global warming potential.

It represents the impact of greenhouse gases that cause the greenhouse effect due to some of the infrared rays radiating from the surface of the earth being absorbed, with CO_2 as the baseline (1.0). The smaller the number, the less of a greenhouse effect there is.

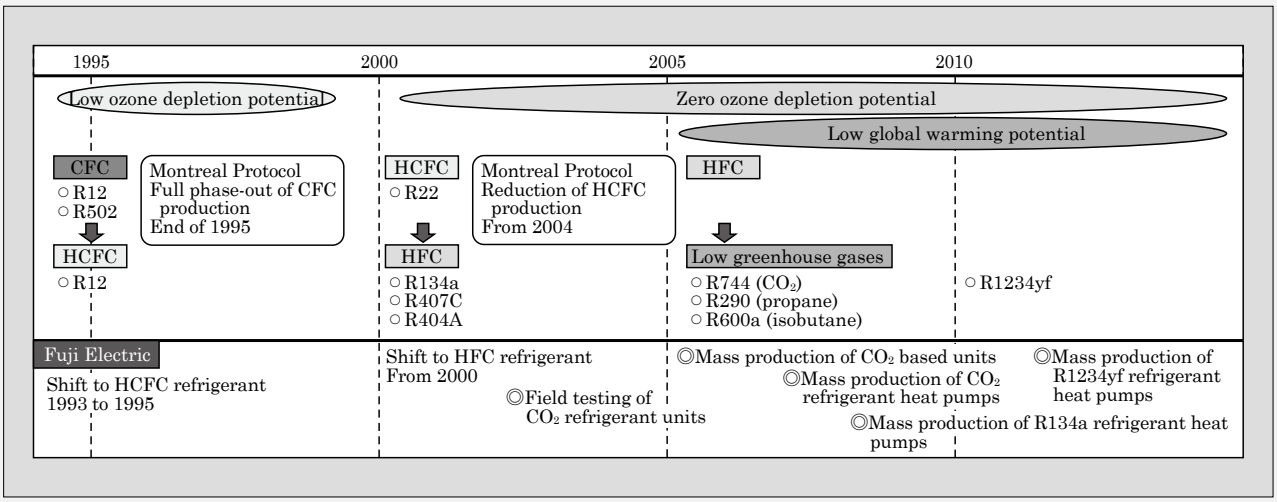

Fig.9 Refrigerant transitions

early stage (1993), with the goal of preserving the global environment (see Fig. 9).

We will successively apply the technologies for energy saving and use of low GWP refrigerants that we have accumulated through developing vending machines to stores and distribution-related products.

3.4 Next-generation showcase with built-in refrigeration system

As shown in Fig. 10, showcases installed in convenience stores and other locations currently use a refrigerator placed outside the store for central refrigerant circulation (showcases with separate refrigeration system).

Fuji Electric has used low GWP refrigerant applied technology to develop a next-generation showcase with a built-in refrigerator (see Fig. 11).

Currently, separate models use R404 A refrigerant, which has a GWP of 3,920. The refrigerant used in our newly developed next-generation showcase has a GWP of 1 or less (the same value as CO_2 refrigerant or less).

We revised the conventional air curtain system to rectify air flow within the housing, resulting in a subdivided airflow system that curbs outside air from being pulled in. This achieves a 30% reduction in required refrigerating capacity over conventional systems.

Compared with separate models whose refrig-

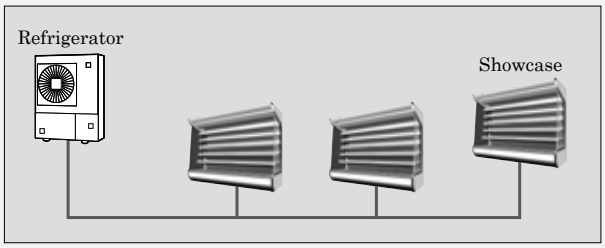

Fig.10 Showcase with separate refrigeration system

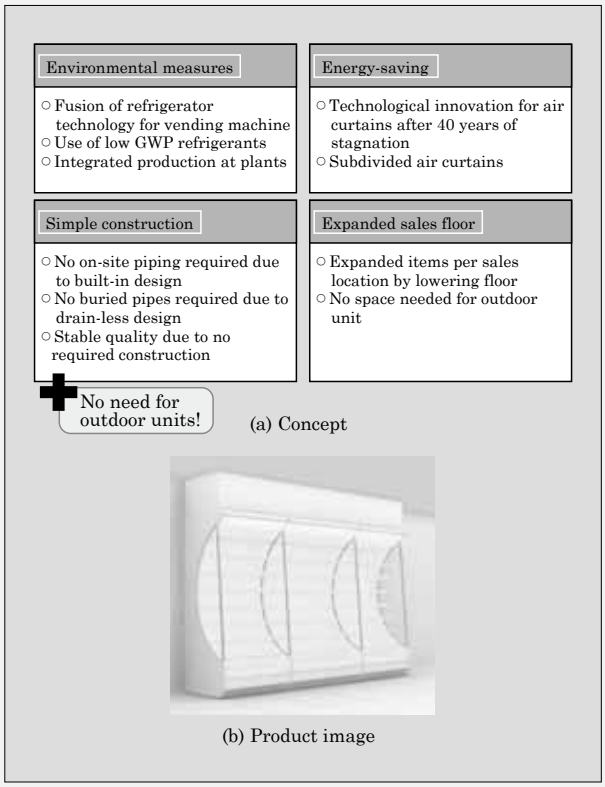

Fig.11 Next-generation showcase with built-in refrigeration system

***7: Ozone depletion potential (ODP)**

ODP stands for ozone depletion potential.

ODP is a coefficient representing the relative value of the destructive effect that unit weight substances released into the atmosphere have on the ozone layer, with CFC-11 (trichlorofluoromethane, CCl3F) set at a value of 1.0. Alternative fluorocarbons that do not include chlorine and the natural refrigerant CO_2 have an ozone depletion potential of 0.

erant pipe is installed in the store, a refrigeration circuit is installed for each showcase, reducing the total amount of refrigerant and making inspection easier. Furthermore, no coupler or mechanical seal work is required on site and brazing keeps circuits completely closed, significantly reducing the danger of refrigerant leaking. Even if refrigerant does leak, the amount will be slight, thus reducing the burden of managing refrigerant.

4. Element Technologies in Global Support of Vending Machines

Fuji Electric has vending machine manufacturing sites in Thailand and China. We proceed with globalization under a 3-site system, with our Mie Factory as the mother factory. In order to quickly respond to circumstances in each country, we have worked hard to shorten the development period by continuing to advance the establishment of our global platform[*8], in which we keep an eye on each requirement and take common points into consideration.

Prior to this, we promoted platform design in Japan, and worked to improve reliability and quality by making parts common and standardized between device categories. As a result of our efforts, around 50% of the components that go into different device categories are common. We will continue to develop these activities across the world, and promote the implementation of the global platform.

4.1 Product dispensing mechanism for the global market

AC power supply solenoids were used as drive sources for mechanisms to dispense cans and bottles. It was therefore necessary to support circumstances from region to region, such as unstable power supplies and differences in power supply voltages. Using DC motors allows us to share dispensing mechanisms among products and also makes it easier to support safety standards in each country (see Fig. 12).

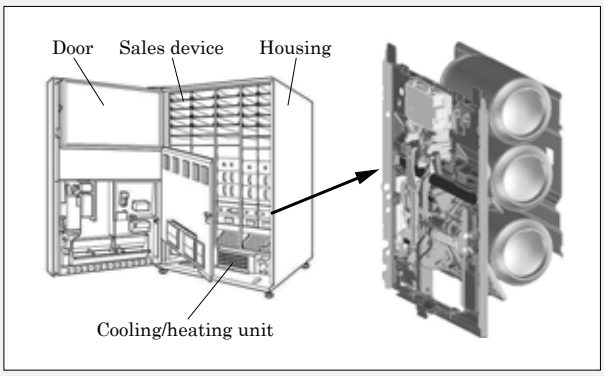

Fig.12 Product dispensing mechanism for the global market

As an added function, it is also possible to verify product dispensing status, dramatically reducing the number of malfunction support calls in the market (refer to "Product Dispensing Mechanism for Vending Machines for Global Market" on page 187).

4.2 Currency identification devices for global markets

In developing currency identification devices to support currency in China and the Association of Southeast Asian Nations (ASEAN) region, we investigated the currencies of each country, and we have improved production efficiency and shorten the development period by clarifying the fixed and variable parts.

Additionally, we have worked to reduce barriers to training new service personnel outside of Japan, such as developing new proprietary sensors and streamlining structures to improve serviceability (refer to "Currency Identification Device for Global Markets 'FGC Series' and 'FGB Series'" on page 196).

4.3 Global vending machines installed in high-temperature high-humidity environments

One important element of vending machines is cooling and heating functions. In order to reduce lost sales opportunities as much as possible, it is important to bring replenished products to their appropriate temperatures quickly.

In the Japanese criteria, required cooling performance is guaranteed assuming the ambient temperature of 32 °C. The same performance is required in environments reaching 40 °C outside of Japan especially in tropical region of Asia. For this reason, we have combined a sophisticated heat exchanger with a CO_2 refrigerant compressor in an attempt to improve cooling performance. We will be committed to achieve the performance required by the circumstances in each region by combining these cooling and heating components as a unit (refer to "Cooling Technology for Global Vending Machine Installed in High-Temperature High-Humidity Environments" on page 202).

5. Postscript

Needs for food distribution businesses are expected to grow more diverse.

***8: Global platform**

Global platform in this sense refers to common components that serves as a foundation for groups of products, in order to expand on a global level. It is separate in meaning from the computer term, which is often used to refer to the act of clarifying and categorizing which OS a computer system belongs to.

In order to remain sensitive to market changes and respond quickly, we will continue to accumulate basic technologies and engage in research and development to meet the needs of the market.

Heat Pump Vending Machine Equipped with CO_2 Ejector Refrigerating Cycle

TSURUHA, Takeshi* YAMAGAMI, Yuhei* MATSUBARA, Takeshi ‡

ABSTRACT

Fuji Electric has been utilizing CO_2 refrigerants and hydrofluorocarbon refrigerants in the refrigeration units used in its beverage vending machines. However, compared with hydrofluorocarbon refrigerants, CO_2 refrigerants have a higher operating pressure and thus require a larger amount of power to drive the compressor. To solve this issue, We have adopted an ejector to recover the lost energy by using the high operating pressure, developed a refrigeration unit that optimally control the ejector, and fitted it into our vending machines. Coefficient of performance (COP) improvement in the refrigeration unit has enabled the vending machine to reduce power consumption by 25% compared with conventional ones.

1. Introduction

Fuji Electric has developed a beverage vending machine that utilizes an ejector*1 for its CO_2 refrigerant based refrigeration unit as a non-fluorocarbon based measure to suppress global warming. The unit achieves power savings of 25% compared with previous products. We achieve higher efficiency and reduce the power of the compressor by utilizing the high pressure of the CO_2 refrigerant as a means to recover conventionally lost refrigerant energy.

2. Development Background

Fuji Electric has been working on reducing power consumption of its beverage vending machines, one of the reason for which is that they have been added to the specified equipment based on the "Act on the Rational Use of Energy" (Energy Conservation Act) since 2002. Presently, 80 to 90% of the power consumption of beverage vending machines is used to heat or cool beverages. One of the principle technologies used thus far in reducing power consumption has been heat pump technology, which Fuji Electric developed and adopted for its products in 2008. Refrigerants for beverage vending machines include CO_2 refrigerants and hydrofluorocarbon refrigerants. When comparing both refrigerants, the CO_2 refrigerant has lower global warming potential, but it requires a larger amount of compression work*2 due to its high operating pressure, thus resulting in reduced efficiency.

In general, efficiency improvements for components such as heat exchangers have come close their limit, but in order to enhance efficiency even further, ejectors have been increasingly adopted in vehicle-mounted refrigeration units and water heaters. We have successfully developed an ejector based refrigerating cycle for our beverage vending machines, and we are aiming to contribute to the suppression of global warming through the use of non-fluorocarbon refrigerants by making use of the characteristically high pressure of CO_2 refrigerants.

3. Development Goals and Challenges

3.1 Challenge of achieving energy savings under actual use conditions

General-purpose vending machines are designed with 3 partitioned compartments. Depending on the season, these compartments can be utilized for cooling or heating as shown in Fig. 1. Most of the vending machine's power consumption is used to maintain the temperature of its products.

The method for measuring the energy efficiency of

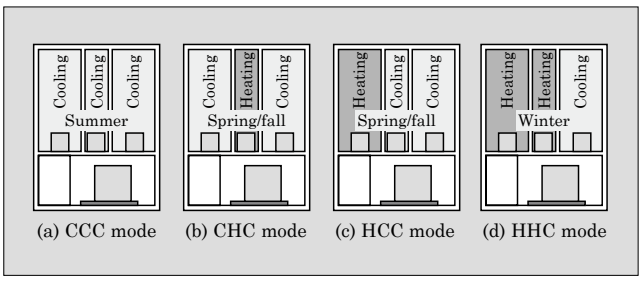

Fig.1 Beverage vending machine seasons and driving modes

*1: Ejector: Refer to "Supplemental explanation 1" on page 207.

*2: Compression work: This refers to the thermodynamic energy required in driving the compressor.

* Food & Beverage Distribution Business Group, Fuji Electric Co., Ltd.

‡ Corporate R&D Headquarters, Fuji Electric Co., Ltd.

beverage vending machines has been set forth in JIS B 8561:2007. The standard defines that power consumption shall be measured based on the spring and autumn cooling and heating mode (HCC mode) in which the left compartment is heated and the center and right compartments are cooled.

One challenge has been to reduce peak power consumption during the summer while also improving the amount of yearly power consumption as measures to respond to social demands following the Great East Japan Earthquake.

We have decided to tackle the latter item, reduction of yearly power consumption, by balancing the coefficients of performance (COP) of refrigerator cooling operation (CCC mode) and heat pump operation (HCC mode) so that both COPs are maximized.

3.2 Points regarding energy consumption reduction

As shown in Fig. 2, the use of refrigerants in beverage vending machines requires heat to be emitted to the outside air. In this respect, the radiator refrigerant temperature must be approximately 10 K higher than the installation environment temperature, corresponding to a range between approximately 30 °C and 50 °C. General fluorocarbon refrigerants have a pressure of approximately 1 to 3 MPa. On the other hand, CO_2 refrigerants are characterized by critical points at a pressure of 7.4 MPa and temperature of 31 °C, and as a result, pressure needs to be in a supercritical state between 8 and 10 MPa to raise a temperature higher than the outside air temperature required in heat radiation. This, in turn, generates a high pressure difference for the compressor's refrigerant compressor component. As a result, the power energy for refrigerant compression increases, and this results in decreased energy efficiency.

Conventionally, countermeasures have been taken, which include the installation of a larger radiator or internal heat exchanger, or the adoption of a 2-stage compression circuit. However, this resulted in a reduction in COP to about 60% of that of refrigeration units utilizing hydrofluorocarbon refrigerants. As a means of rectifying this, we have utilized an ejector to achieve COP improvements.

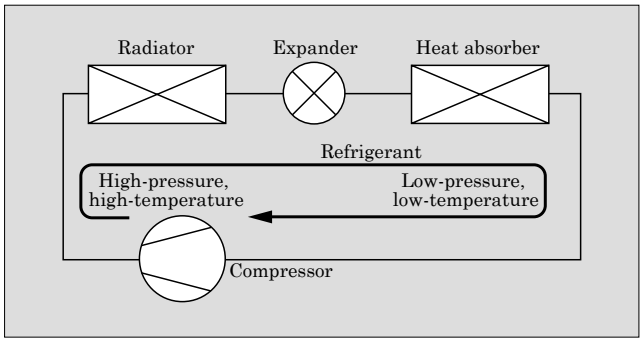

Fig.2 Basic principles of refrigeration unit

4. Configuration and Newly Adopted Technology for the Ejector Mounted Heat Pump Refrigeration Unit

4.1 Development tasks

The purpose of our development work this time has been to maximize COP for heating and cooling operations. To achieve this, we established the following development tasks.

(a) Theoretical value for ejector effectiveness when utilizing a CO_2 refrigerant
(b) Application of the ejector in the refrigeration circuit of beverage vending machines that utilize 3 evaporators in parallel
(c) Application of ejectors used in water heaters to beverage vending machines
(d) Securing reliability for the installation environment of beverage vending machines

4.2 Theoretical value for ejector effectiveness when Utilizing a CO_2 Refrigerant

Figure 3 shows the internal configuration of the developed ejector. The refrigerant flowing into the ejector as driving flow increases in flow velocity when passing through a nozzle with a narrow diameter. Since pressure decreases as flow velocity increases, a force for drawing fluid from the suction flow side is generated. Two fluids converge in the mixing component, and then the diffuser reduces the velocity and increases the pressure. Design was made so as to minimize turbulence in the passage, and this has enabled us to maximize the effects shown below.

Figure 4 shows the refrigeration cycle diagram of conventional CO_2 refrigerant based beverage vending machines. The horizontal axis represents enthalpy, and the vertical axis represents pressure. The expansion process of the refrigeration cycle changes from isenthalpic expansion to ideal isentropic expansion, that is, expansion with no fluid turbulence to reduce energy loss. The figure shows that the cycle recoveries the energy loss caused by turbulence and reduces compressor driving power.

The effectiveness of using the ejector was calculat-

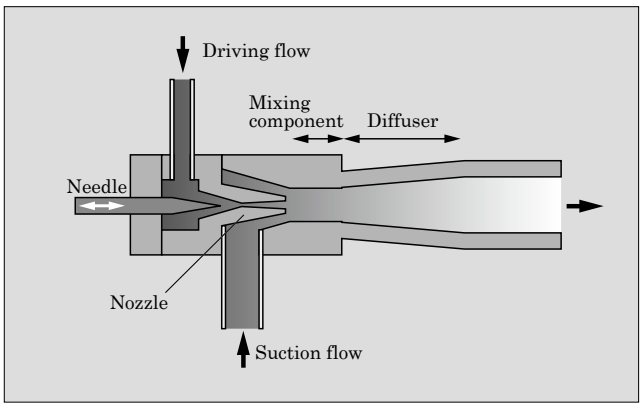

Fig.3 Internal configuration of ejector

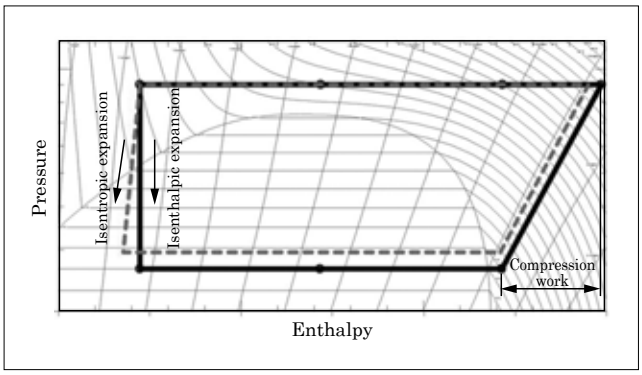

Fig.4 Refrigeration cycle diagram of CO_2 refrigerant based beverage vending machines

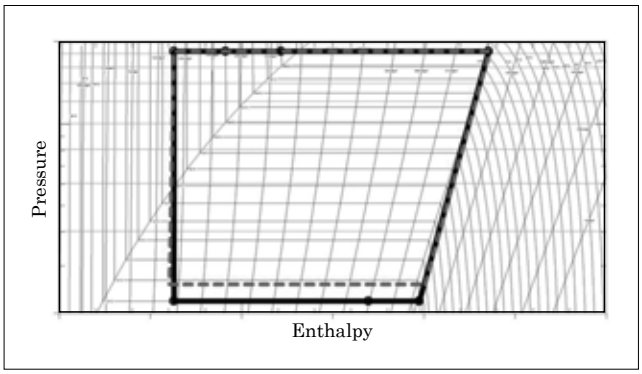

Fig.5 Refrigeration cycle diagram of hydrofluorocarbon refrigerant based beverage vending machines

ed with regard to energy loss. When there is no turbulence in the pressure reducing expansion process, isentropic change occurs, and the reduction in compression work, corresponding only to the pressure difference after expansion, is lower than the isenthalpic change. When the evaporation temperature is at −10 °C, high pressure at 9.0 MPa, gas cooler outlet temperature at 40 °C, internal heat exchanger high-pressure outlet temperature at 20 °C and compressor suction overheat temperature at 5 K, the difference due to the presence of the ejector results in a 3.1 kJ/kg reduction in theoretical compression work and a 10.3% improvement in COP.

On the other hand, Fig. 5 shows the same effectiveness calculation using a hydrofluorocarbon refrigerant. The rise in the compression work reducing effect was 4.2%, which is lower than that of the CO_2 refrigerant. The ejector has demonstrated its increased effectiveness for reducing compression work for CO_2 refrigerants.

4.3 Application of the ejector in the refrigeration circuit of beverage vending machines that utilize 3 evaporators in parallel

Figure 6 shows the refrigeration circuit of the CO_2 refrigerant heat pump (HCC mode). Figure 6(b) shows a circuit that utilizes an ejector. In addition to adding an ejector and gas-liquid separator, it also

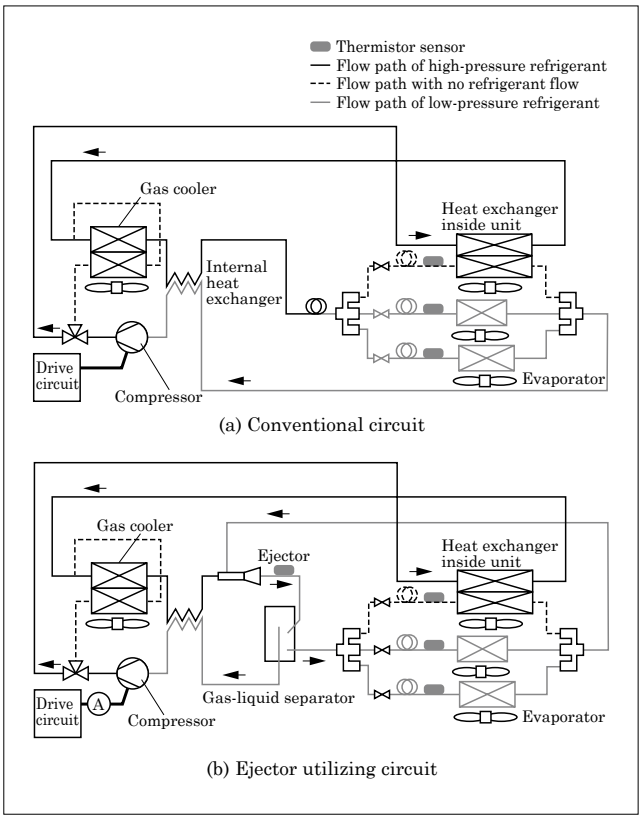

Fig.6 Circuit of CO_2 refrigerant based heat pump refrigeration unit (HCC Mode)

equips the ejector outlet with a thermistor sensor and the compressor drive circuit with an ammeter. The gas-liquid separator is designed to return the liquid phase portion of the low-pressure refrigerant ejected from the ejector to the evaporator, and the remaining portion to the compressor. When this happens, the refrigerator oil, which outflows to the evaporator side with the liquid phase refrigerant, must be returned to the compressor side. To achieve this, we designed the unit with several special features such as an oil return mechanism.

4.4 Application of ejectors used in water heaters to beverage vending machines

Beverage vending machines adopt variable needle ejectors developed for use in beverage vending machines based on the ejectors used in water heaters. Table 1 shows the difference in specifications between

Table 1 The Difference in specifications between water heater and beverage vending machine refrigeration units

Item	Water heater	Beverage vending machine
Refrigerant circulation rate	50 kg/h	7 kg/h
Application	Heating	Heating and cooling
No. of evaporators	1	3
No. of stops per day	Several times	Several tens times

water heater and beverage vending machine refrigeration units.

The refrigerant circulation rate in the vending machine is only about one-seventh of that of water heaters, and hence it is necessary to almost completely close the valve opening of the variable needle. Furthermore, the vending machine was designed with 3 evaporators installed in parallel as shown in Fig. 6. In order to properly maintain the refrigerant circulation rate corresponding to rapid changes resulting from compartment heating and cooling switchover operations, the unit is required to have highly responsive control at a low flow rate.

Therefore, we designed the unit to implement feedback control as it measures the physical quantity for quickly responding to the control rate of the ejector. The physical quantity has been configured so as to use the input current of the compressor and the temperature of the ejector outlet.

4.5 Cooling & heating capacity and COP maximization

As mentioned in the development goals stated in Chapter 3, there is a need to strike a balance between the COPs of refrigerator cooling operation (CCC mode) and heat pump operation (HCC mode) so that both COPs are maximized. However, there is only one circuit, and since the refrigeration filling amount cannot be changed according to season, changes in the refrigerant circulation rate, required as a result of these load differences, were accommodated by adjusting the rotational speed of the compressor and the valve opening of the ejector.

Figure 7 shows an example of the results of measuring the heating COP and cooling COP in HCC mode. This example shows the COP at the time of adjusting the valve opening of the ejector in HCC mode when both heating and cooling are required at the same time. Adding the heating COP and the cooling COP gives a total COP that is more than 124% of previous products. We also found that it is possible to control valve opening corresponding to load fluctuation to adjust the cooling capacity and heating capacity.

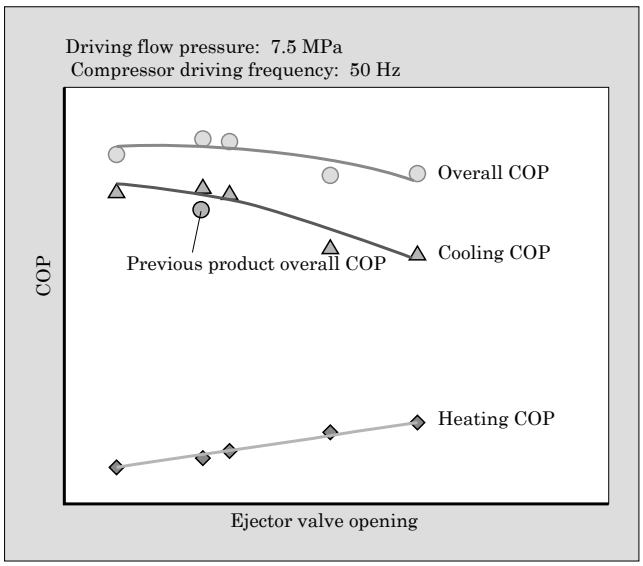

Fig.7 Example of results of measuring heating COP and cooling COP in HCC mode

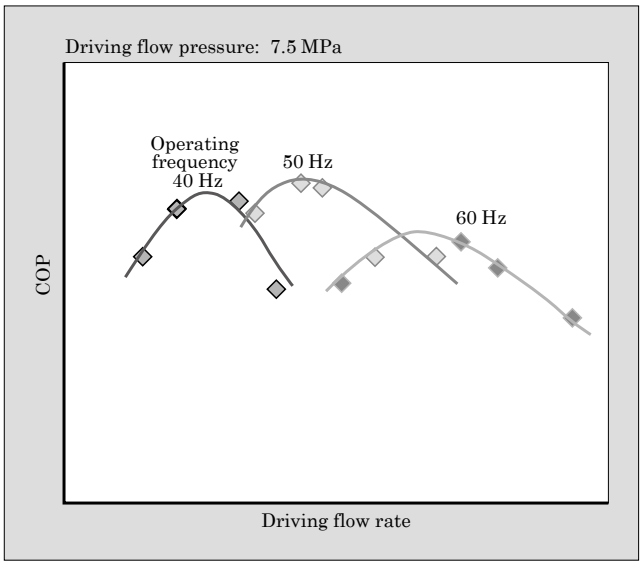

Fig.8 Example of COP measurement for each compressor drive frequency

Figure 8 shows an example of the results of measuring COP when there are changes in the valve opening of the ejector and operating frequency of the compressor. These characteristics showed that by properly controlling the valve opening and operating frequency of the compressor and by optimizing driving flow, it is possible to maximize COP while also maximizing ejector capacity.

Therefore, we determined the optimal evaporation temperature and compressor operating frequency as parameters for heating loads measured from the ambient temperature and internal temperature of the unit. Following this, we implemented control by performing micro adjustment of the valve opening of the ejector so as to obtain the designated evaporation temperature. When there is large load fluctuation such as changes in the number of cooling compartments, feedback control is performed while detecting the ejector outlet temperature and evaporator inlet temperature. In addition, further correction is made while detecting the input current of the compressor used for monitoring pressure, and control is made so as to maintain the cooling cycle at maximum efficiency.

4.6 Securing reliability for installation environment of beverage vending machines

As shown in Table 1, beverage vending machines start and stop 10 times more often per day than water heaters. The ejector outlet temperature in beverage vending machines is constantly below the freezing point. During operation, atmospheric moisture freezes, but thaws when the unit stops. If there is bonding fail-

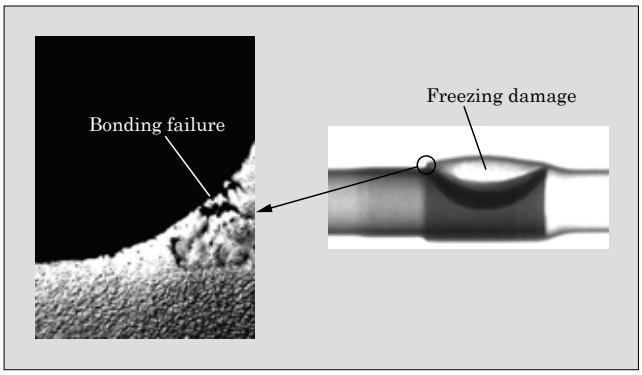

Fig.9 Example of brazing portion bonding failure and freezing damage

ure, such as void or shrinkage cavities, on the brazing portion of parts, moisture deposits in such areas will repeatedly expand and contract in volume due to freezing and thawing, and it is well known that this can lead to freezing damage as shown in Fig. 9.

Therefore, we implemented final quality assurance by carrying out repeated process verification and actual machine verification utilizing methods such as detailed cross-sectional observation.

5. Performance of Beverage Vending Machines

5.1 Energy savings performance

Table 2 shows the performance of a beverage vending machine mounted with the new technology based device. Although it was considered difficult to further increase efficiency in CO_2 refrigerant based refrigeration units, we achieve a COP improvement of 124% in HCC mode and 140% in CCC mode. Furthermore, with regard to heat pump type vending machines that utilize an internal heat exchange system, we significantly reduce disparities with hydrofluorocarbon refrigerant based refrigeration units. This development results in the following achievements: annual power consumption of 440 kWh/y based on the measuring method set forth in JIS B 8561:2007; an achievement rate of 242% compared with the Energy Conservation Act's top runner standard value of 1,068 kWh/y; and the highest level of energy savings for vending machines even when compared with low-pressure refrigerants having the same internal capacity.

Table 2 Performance of beverage vending machine mounted with a CO_2 refrigerant based refrigeration unit

Item	Developed unit	CO_2 heat pump 2	CO_2 heat pump 1
Refrigerant	CO_2		
Compressor drive system	Variable speed	Variable speed	Constant speed
Heat pump circuit	Yes	Yes	Yes
Ejector	Yes	No	No
Cooling/heating COP ratio	1.57	1.25	1
Cooling COP ratio	1.41	0.97	1
Launch time	Apr. 2015	Dec. 2014	Nov. 2011
JIS display value*	440 kWh/y	585 kWh/y	895 kWh/y
Top-runner standard value	1,068 kWh/y	1,081 kWh/y	1,086 kWh/y
Top-runner achievement rate	242%	184%	121%

*JIS display value: A value based on the measurement method provided in JIS B 8561:2007 classification III

5.2 Future developments

We have achieved extensive COP improvements for refrigeration units utilizing ejectors. However, as shown in the refrigeration cycle diagram in Fig. 4, in order to make optimal use of this effect, the units should be operated during the expansion process at an even higher enthalpy point. In the future, we would like to utilize our applicable technologies in water heaters to achieve heating-only operation of the CO_2 refrigerant based refrigeration units in vending machines, a feat that up until now has been considered very difficult to do.

6. Postscript

The use of an ejector mounted to the refrigeration unit of beverage vending machines utilizing environmentally friendly and natural CO_2 refrigerants makes it possible to further expand the energy savings of CO_2 refrigerants. We believe that this current development contributes to suppressing global warming by improving the COP of the refrigeration unit. As mentioned in the Future Developments section, however, we believe that there is still room for improving the performance of the heating component of vending machines. Applying this cycle to the heating component will help to overcome the weaknesses of current heat pumps, and as a result, further contribute to suppressing global warming.

Finally, we would like to express our appreciation to DENSO Corporation for their efforts and support in developing this device.

ZERO Heating Power Vending Machine "Hybrid ZERO"

ISHIDA, Shin*

ABSTRACT

Fuji Electric has adopted the concept of achieving extensive energy savings while reducing peak power consumption to decrease environmental burdens, and based on this, it has developed the ZERO Heating Power Vending Machine "Hybrid ZERO" as a unit that does not utilize an electric heater. Conventionally, a portion of the storehouse has been heated using an electric heater, but the Hybrid ZERO heats all heating chambers using a heat pump. We have achieved this functionality by increasing the efficiency of heat exchangers and compressors while newly developing a refrigerant path switching valve. These enhancements have enabled the Hybrid ZERO to achieve a 15% reduction in yearly power consumption based on estimated actual usage in its operation modes, as well as a maximum power consumption reduction of 55% during winter operation mode.

1. Introduction

Fuji Electric has adopted the concept of achieving extensive energy savings while reducing peak power consumption for its vending machines, and based on this, it has developed the ZERO Heating Power Vending Machine "Hybrid ZERO." The product name Hybrid ZERO is based on the following 2 points:

(a) Application of hybrid heat pump technology

It uses both the waste heat generated when cooling beverages and the heat of the outside air as heat sources for heat pump heating.

(b) Utilization of no electric heater power

Since the heating of all hot beverages is exclusively carried out by the heat of the heat pump, there is no need to mount an auxiliary electric heater.

Hybrid ZERO performs cooling and heating by means of a heat pump for all four seasons, thus enabling it to achieve a 15% reduction in yearly power consumption*1, as well as a maximum power consumption reduction of 55% during winter operation mode compared with previous hybrid heat pump beverage vending machines. This paper describes the challenges and work we undertook in the development of the Hybrid ZERO.

2. Development Background

We have been actively pursuing the development of energy-saving technology for vending machines ever since can-and-bottle type vending machines were designated as special equipment in the "Act on the Rational Use of Energy" (Energy Conservation Act) in 2002. Furthermore, power shortages following the Great East Japan Earthquake in March 2011 created the need for a 25% reduction in peak power consumption, and as a result, energy-saving measures were taken such as lighting control and rotational-based cooling-mode operation stoppages of vending machines. Against this backdrop, the vending machine industry has been working to achieve energy savings to reduce environmental burdens, while also responding to demands for reduced power consumption to improve the supply and demand balance for electric power.

Fuji Electric has developed technology capable of achieving extensive energy savings and power consumption reduction benefits.

3. Development Goals and Challenges

3.1 Challenge of achieving energy savings under actual use conditions

Figure 1 shows the structure of a vending machine. General-purpose vending machines are designed with 3 partitioned compartments (left compartment, center compartment and right compartment) for storing beverages, and depending on the season, these compartments can be configured for use in cooling or heating operation mode. Table 1 shows the settings for 4 operation modes. Operators can configure their vending machines to match the purchasing needs of consumers. For example, it is common to set a vending machine to CCC mode (cooling operation for all 3 compartments) during the summer when cold drinks sell well, to HHC mode (heating operation for 2 compartments and cool-

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*1: Amount of yearly power consumption: Measurement of the amount of yearly power consumption is based on an uniquely defined power measuring method.

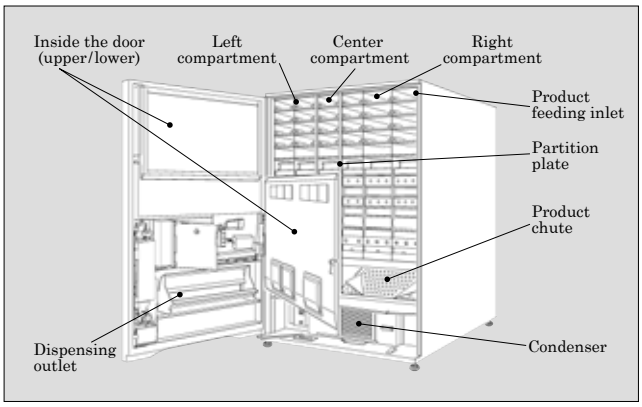


Fig.1 Structure of vending machine

Table 1 Operation modes and cooling/heating settings for each compartment for conventional machines

Operation mode	Left compartment	Center compartment	Right compartment
CCC mode	Cooling	Cooling	Cooling
HCC mode	Heat-pump heating	Cooling	Cooling
CHC mode	Cooling	Electric-heater heating	Cooling
HHC mode	Heat-pump heating	Electric-heater heating	Cooling

ing operation for one compartment) during the winter when hot drinks sell well, and to HCC mode (heating operation for one compartment and cooling operation for 2 compartments) in the spring and fall.

Conventional machines have used heat pump operation for beverages in the left compartment as a means of providing more effective heating compared with an electric heater. Using a heat pump instead of an electric heater to heat the center compartment could produce energy savings, but the actualization of this has been difficult for the following reasons.

(a) Since there is insufficient space in the center compartment, it has not been possible to install an appropriately sized heat exchanger for heating.
(b) The size of refrigeration units has been increasing due to the greater complexity of refrigerant circuits and the increasing number of switching valves.

3.2 Points regarding the reduction of the amount of yearly power consumption

Figure 2 shows the percentage of power consumption for conventional machines which commonly use the 3 main operation modes. The percentages are the largest for the compressor used in CCC mode and HCC mode, and for the electric heater used in HHC mode. It is possible to reduce the electric energy pertaining to the compressor by increasing the efficiency of compression, and the electric energy pertaining to the electric heater by using a heat pump instead. In other

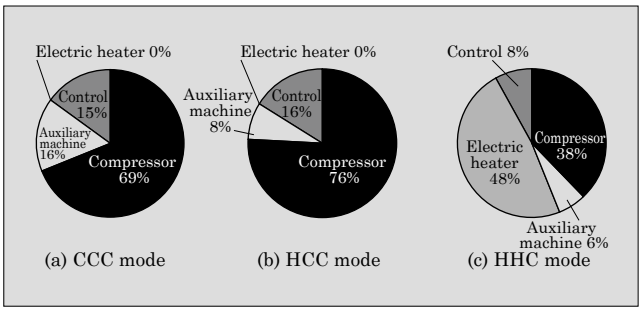


Fig.2 Percentage of power consumption in main operating modes of conventional machines

words, the following 2 points contribute to reducing the amount of yearly power consumption.

(a) Higher efficiency for the compressor
(b) Simultaneous heat-pump based heating for heating compartments in HHC mode (left compartment and center compartment)

However, the use of heat-pump based heating for the center compartment faces several problems as described in Section 3.1 above. These include the need for a larger installation space due to the complexity of the circuit structure of the refrigeration unit, as well as the problem of excessive discharge pressure resulting from the insufficient capacity of a heat exchanger being installed in the narrow center compartment. Furthermore, there also exists the problem of not being able to secure the capacity needed to use a heat pump to heat both the left compartment and center compartment simultaneously. Summarizing these challenges, we are confronted with the following 3 tasks.

(a) Streamlining the devices that make up the refrigeration circuit
(b) Securing heating capacity by simultaneously heating 2 compartments with a heat pump
(c) Suppressing excessive discharge pressure generated in heating the center compartment with a heat pump

4. "Hybrid ZERO" Refrigeration Unit Structure and Technology

4.1 Streamlining the devices that make up the refrigeration circuit

In order to reduce the amount of power consumed when using an electric heater, we have constructed a refrigeration circuit for heating the center compartment with a heat pump.

Figure 3 shows the switching of the discharge piping for the compressor in the refrigeration circuit of a conventional machine. In a conventional machine, the refrigerant was only able to flow through one of 2 paths, that is, either through the path of the condenser used for the cooling operation, or through the path of the left-compartment heat exchanger used for heating with a heat pump.

On the other hand, the Hybrid ZERO, which is ca-

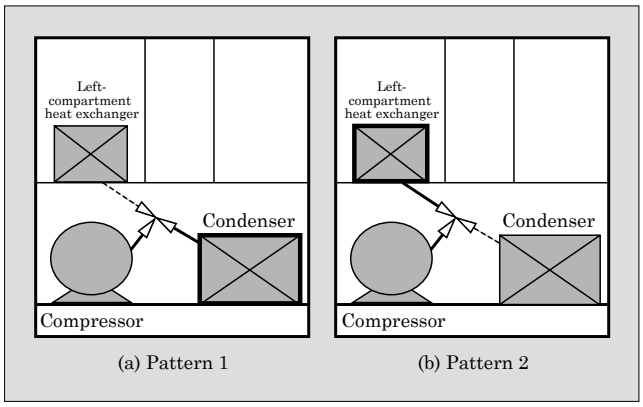


Fig.3 Switching of discharge piping for the compressor in refrigeration circuit of a conventional machine

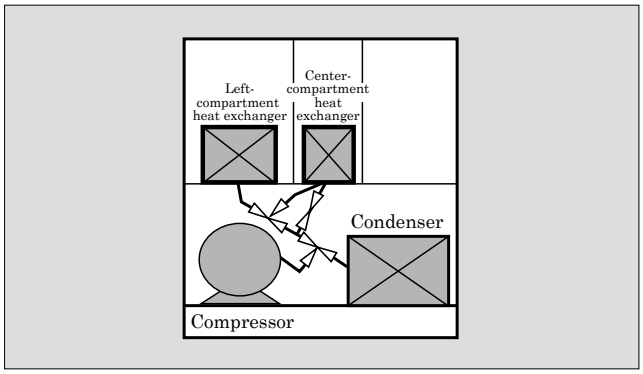


Fig.4 Discharge piping for achieving simultaneous heating of 2 compartments using conventional switching valves

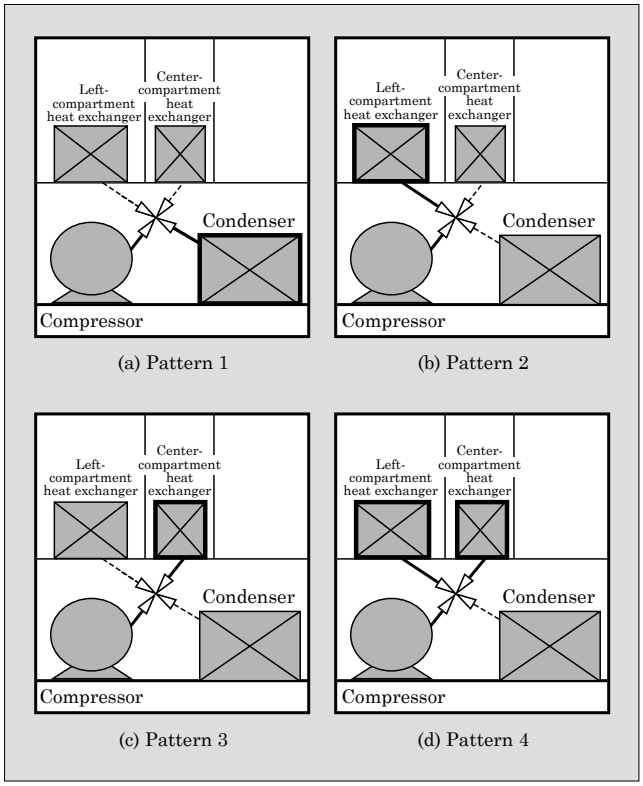


Fig.5 Switching of discharge piping in “Hybrid ZERO”

pable of using a heat pump to heat both the left compartment and center compartment simultaneously, has been designed with 3 connection destinations for the compressor discharge piping, which include the conventional destinations for the condenser and left-compartment heat exchanger, while also now including the center-compartment heat exchanger. In order to enable heating with a heat pump for the center-compartment heat exchanger, there are now twice as many switching paths.

Configuring the refrigeration circuit with the conventional switching valve created the problem of an increased size for the refrigeration unit, resulting from an increase of 2 switching valves compared with conventional machines as shown in Fig. 4.

Therefore, we newly developed a 4-way valve, which is a stepping motor type flow-path switching valve, to implement switching, as shown in Fig. 5. This enhancement has enabled us to suppress the increase in valves. By doing this, we were able to decrease the space of the refrigeration unit by about 15% compared with designs that utilize conventional valves.

4.2 Securing heating capacity by simultaneously heating 2 compartments with a heat pump

In HHC mode, conventionally applying the single compartment heat-pump heating capacity to 2 compartments (left compartment and center compartment) would cause the heating capacity per compartment to be halved. In general, all that is needed to increase the heating capacity is to increase the rotational speed of the compressor. However, an increase in the rotational speed causes degradation in the efficiency of the compressor, so there has been a need to increase the efficiency of the refrigeration unit.

We have solved this problem by switching to a circuit in which the compressor sucks in the refrigerant in a manner that makes more effective use of the waste heat of the compressor. This technique is explained as follows. General reciprocating compressors have 3 ports as shown in Fig. 6. These include the suction port for sucking in the refrigerant, the discharge port for discharging the compressed refrigerant and process port for services.

A suction muffler is mounted to the suction port,

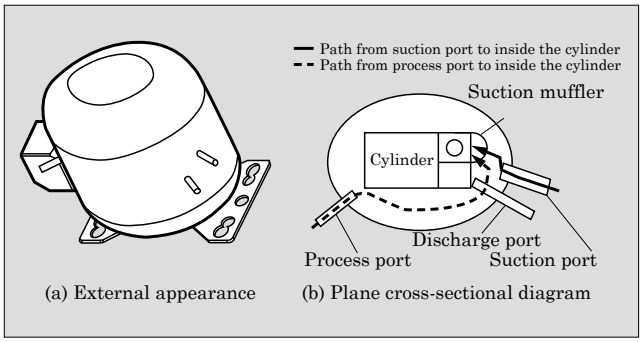


Fig.6 Compressor

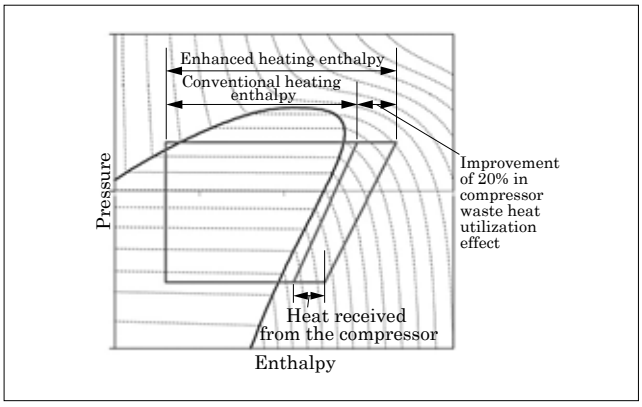


Fig.7 Waste heat utilization effect of compressor

and refrigerant sucked from the suction port into the compressor reaches the inside of the cylinder by following the shortest path as shown in Fig. 6. Therefore, the heat that the refrigerant receives from the high-temperature compressor is minimized, and as a result, there is very little temperature rise compared with the refrigerant temperature before compression. This effect makes it possible to implement a highly efficient cooling operation in which the discharge temperature is not likely to rise since the refrigerant is sucked in from the suction port. On the other hand, when there is no suction muffler on the process port, the path until the refrigerant, which is sucked in from the process port, reaches the inside of the cylinder becomes long, and thus the amount of heat the refrigerant receives from the compressor is large. As a result, the method of sucking in refrigerant from the process port causes a larger discharge temperature, and as such, it is easy to increase the capacity of the heat-pump heating.

However, the adoption of a refrigeration circuit in conventional machines to suck in refrigerant from the suction port during either refrigeration operation or heat pump operation makes it difficult to obtain the heating capacity during heat pump operation. Therefore, the Hybrid ZERO utilizes a refrigeration circuit capable of switching the port that sucks in the refrigerant depending on the operation. During refrigeration operation, it switches the port to the suction port, and during heat pump operation, it switches the port to the process port not equipped with a suction muffler. The result of this is that the waste heat of the compressor can be effectively used as shown in Fig. 7, while also increasing the heating capacity of the heat pump by 20%. By combining this effect with the increase in the rotational speed of the compressor, system efficiency is maintained and it becomes possible to implement simultaneous 2 compartment heating with a heat pump.

4.3 Suppressing excessive compressor discharge pressure generated in heating the center compartment with a heat pump

When adopting a refrigeration circuit capable of simultaneous 2 compartment (left compartment and center compartment) heating with a heat pump, it is possible to use stand-alone heat-pump heating for the center compartment. However, this creates the problem of excessive pressure.

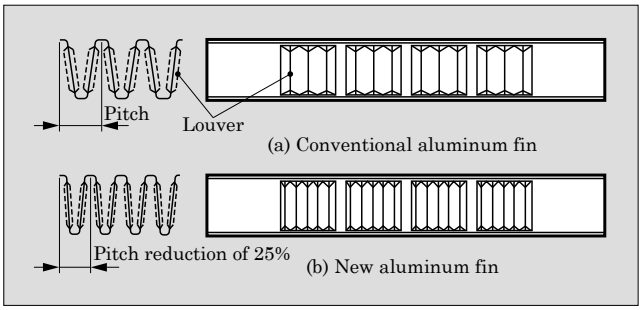


Fig.8 Conventional aluminum fin and new aluminum fin

In general, the center compartment is the smallest among the 3 compartments in a vending machine, and thus, it also provides the smallest amount of space for installing a heat exchanger. As such, excessive pressure is generated without the ability for the heat exchanger to create sufficient heat radiation for the flowing refrigerant. Therefore, we adopted the countermeasure of increasing the efficiency of both the heat exchanger and the compressor.

(1) Higher efficiency for the heat exchanger

In 2012, we developed an aluminum-fin fin pitch for our all-aluminum heat exchanger that is 25% narrower than conventional products as shown in Fig. 8. This has resulted in a 25% increase in the heat transfer area without changing the volume of the heat exchanger. Furthermore, we also optimized the shape of the louver of the fin to accommodate the narrow pitch. We verified in a simulation that this new type of aluminum fin achieves an average thermal conductivity improvement of 32%.

(2) Higher efficiency for the compressor

In order to reduce the amount of refrigerant of the center-compartment heat exchanger when heating the center compartment, the easiest and most effective method is to lower the rotational speed of the compressor. However, the minimum rotational speed for conventional compressors is not enough to suppress the excessive rise. Therefore, it became needful to reduce the minimum rotational speed of the compressor. So, in addition to increasing the efficiency, we worked on technology development with compressor makers and have successfully optimized specifications to match the load of vending machines. As a result, we have reduced the minimum rotational speed of the compressor by 12%, and have also achieved about a 10% improvement in efficiency. By adopting this compressor in the Hybrid ZERO, we have been able to sufficiently reduce rotational speed during stand-alone heating for the center compartment, while also suppressing excessive discharge pressure in the compressor and increasing the efficiency of the refrigeration unit.

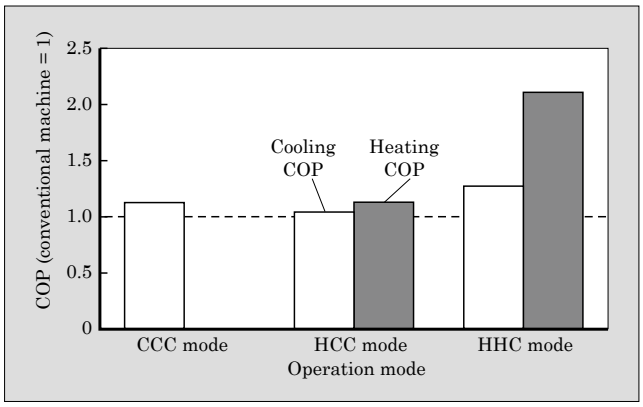


Fig.9 "Hybrid ZERO" COP

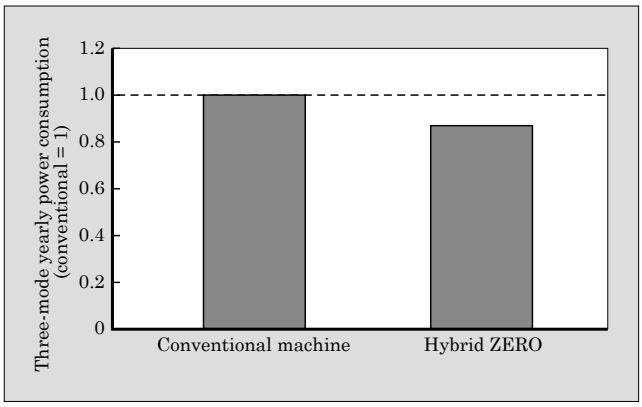


Fig.10 Amount of yearly power consumption in 3 modes for conventional machines and "Hybrid ZERO"

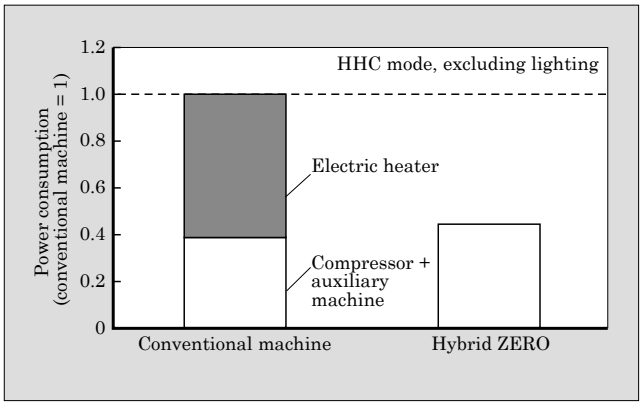


Fig.11 Power consumption for conventional machines and "Hybrid ZERO"

5. "Hybrid ZERO" Performance

5.1 Refrigeration unit performance

We measured the coefficient of performance (COP) to verify the effect of the energy-saving measures that we described above. The COP corresponds to the efficiency of the refrigeration unit mounted on the Hybrid ZERO. The measurement results are shown in Fig. 9. The vertical axis represents the ratio of cooling unit COP compared with conventional machines (conventional machine COP=1). In particular, there was significant improvement in heating efficiency when implementing heat pump operation in HHC mode, and we were able to confirm the considerable effect of using a heat pump for the center compartment.

5.2 Vending machine performance

We calculated the amount of yearly power consumption for the 3 modes to compare its performance with real life conditions (see Fig. 10). Calculation for the amount of yearly power consumption for the 3 modes is based on an assumed operation of 90 days per year for CCC mode (summer), 185 days per year for HCC mode (spring and fall) and 90 days per year for HHC mode (winter). The vertical axis represents the ratio of the amount of yearly power consumption for the 3 modes compared with conventional machines (conventional machine performance=1). The Hybrid ZERO achieves a 15% reduction in the amount of yearly power consumption for the 3 modes compared with conventional machines. In addition, it also achieves a 27% reduction in power consumption according to measurements based on JIS B 8561.

Following this, we measured power consumption in HHC mode to verify the effect of reducing power consumption (see Fig. 11). Similar to the other figures, the vertical axis represents the ratio of power consumption compared with conventional machines (conventional machine power consumption=1). In conventional machines, the power consumption of the electric heater occupied more than 60% of the total unit power consumption, but this source of power consumption has been completely eliminated in the Hybrid ZERO, which suppresses overall power consumption to just 45% of conventional machines. These results have shown that the unit not only achieves yearly power savings, but also is extremely effective in improving the supply and demand balance of power in the winter.

6. Postscript

In this paper, we have introduced the ZERO Heating Power Vending Machine "Hybrid ZERO." The Hybrid ZERO is designed with consideration of the environment, and has achieved considerable energy savings and reduction in power consumption during winter operation mode by adopting a heat pump to heat all heating compartments. It contributes to preventing global warming and also improves the supply and demand balance of energy in Japan.

In the future, we plan on continuing our efforts to achieve energy savings in vending machines while we also strive to develop products that further alleviate environmental burdens.

Office-Use Ultra-Compact Cup-Type Vending Machine "FJX10"

KUROYANAGI, Yasuhiko* ITO, Shuichi* NISHIKAWA, Yohei*

ABSTRACT

Fuji Electric has developed an office-use ultra-compact cup-type vending machine "FJX10" in collaboration with Japan Beverage Holdings Inc., a cup beverage operator. The unit has been designed to be installed in offices, being characterized by its compact size and low power consumption, allowing it to dispense delicious coffee within the premises of an office. Moreover, the unit utilizes a cup mixing system that achieves a superior level of sanitation and ease of cleaning by adopting the industry's first horizontal uniaxial conveyance mechanism. Furthermore, it also achieves an industry top-class low power consumption of 849 kWh/y by means of equipping the unit with a high-efficiency energy-saving ice maker, as well as an energy-saving hot water tank that adopts a vacuum heat insulating structure.

1. Introduction

Cup-type vending machines are operated in a variety of locations, such as offices, factories, hospitals and highway service areas. Approximately half of these are used in offices with many workers. Therefore, most of these are medium, large or multi-functional machines that could not guarantee enough sales to recover the investment made in offices with few workers, and it was also difficult to ensure space for installation.

Meanwhile, counter-top machines developed in 2013 that make use of the regular coffee extraction system, a technology in cup-type vending machines, have been highly rated by consumers for the deliciousness of their beverages, and have resulted in a significant coffee sales boom in convenience stores.

2. Development Background

In consideration of cup-type vending machine market conditions and needs felt in the coffee sales market, Fuji Electric has developed an office-use ultra-compact cup-type vending machine "FJX10" in collaboration with Japan Beverage Holdings Inc., a cup beverage operator, with the goal of revitalizing the office market (see Fig. 1). It features a compact size, and provides familiar and delicious genuine coffee.

3. Development Goals and Challenges

Cup-type vending machines are automatic beverage preparation machines that prepare ready to drink beverages from water and ingredients. In other words, the entire supply chain for packaged beverages, from the manufacturing plant to the sales floor, is complete in a single unit. Cup-type vending machines are therefore composed of mechanisms that perform a variety of functions, such as paper cup supply, hot water and ice cube creation, ingredient supply and coffee extraction.

Fig.1 "FJX10"

In order for cup-type vending machines to be accepted at offices, each mechanism must be more efficiently arranged so that hot and cold beverages can be sold from a unit with a compact size and running costs must be reduced, while ensuring that provided materials are sanitary and safe.

4. Overview of "FJX10"

4.1 Features

(a) New design door for offices
(b) Compact-size, hot and cold specifications
(c) Single cup drip-type coffee brewer that provides delicious coffee
(d) Cup mixing system that prepares materials inside the cup, and offers excellent cleanliness and sanitation

* Food & Beverage Distribution Business Group, Fuji Electric Co., Ltd.

4.2 Specifications

Table 1 lists the specifications for FJX10.

(1) New design door

An integrated membrane keypad with a high level of design freedom is adopted to completely change the concept of traditional cup-type vending machines. The panel display and membrane keypad are integrated in a single unit, resulting in product displays and selection buttons that are reminiscent of menu boards at coffee shops. The left and right molding are made a silver metallic color to give the machine a high grade look, and are made detachable to allow for future renovation.

(2) The most advanced preparation technology in the industry

The machine includes the regular coffee extraction system, Fuji Electric's core technology in vending machines, which played a role in sparking the convenience store coffee boom in 2013. It also adopts the industry's first horizontal uniaxial conveyance mechanism, so that the cup mixing system can be utilized in a compact unit. Finally, it is equipped with a control function to shake a cup during propeller stirring, in order to increase preparation efficiency.

(3) Environmental support

Table 1 "FJX10" specifications

Item	Specification
Model	FJX10
Dimensions	W550×D600×H1,700 (mm)
Product weight	135 kg
Product display/ push buttons	Flavor: 6 types / Product selection: 12 buttons Function: 9 buttons
Sales ingredients	Regular: 2.1 L×2 Cream: 1.4 L×1 Sugar: 1.4 L×1 Powder: 1.4 L×3
Coffee brewer	Drip-type paper filter Dreg bucket capacity: 14 L
Cup mechanism	Nine ounce only, two types (stores 210 cups)
Ice maker storage capacity	2.1 kg
Hot water tank capacity	3.0 L
Water supply	Directly connected to water service/ cassette tank
Drainage bucket capacity	5.5 L
Refrigerant	HFO-1234yf
Power consumption	849 kWh/y

*1: HFO-1234yf: This non-fluorocarbon refrigerant has a low global warming potential (GWP) of 4, and conforms to "Act on Promotion of Procurement of Eco-Friendly Goods and Services by the State and Other Entities" (Law on Promoting Green Purchasing) standards calling for a GWP of less than 140.

The machine has achieved an industry top-class low power consumption of 849 kWh/y by means of equipping the unit with a hot water tank that uses vacuum heat insulating material for high insulation performance and an ice maker with a highly efficient control function. It also adopts an environment-friendly HFO-1234yf[*1] refrigerant that conforms to the Law on Promoting Green Purchasing.

(4) Simple operation

The machine is equipped with an auto sanitation function that rinses the stirring propeller for each cup. The cleaning part is structured so that it can be easily removed and washed.

(5) Improved serviceability and assembly

As the machine features a compact size, each mechanism element is given a block structure to facilitate maintenance and assembly. Each block can be detached and reattached.

5. Energy Saving Technology for Cup-type Vending Machines

5.1 Energy-saving hot water tank

Cup-type vending machines work under a wider temperature range (from 97 °C for hot water to −10 °C for ice cubes) than canned beverage vending machines (from 55 °C for hot beverages to 5 °C for cold beverages). The "Food Sanitation Act" regulates each control temperature to maintain food safety. One issue we faced was to build a system that prioritizes safety and controls the machine to automatically mark products as sold out if they fall outside of these conditions, while maintaining highly efficient cooling, heating and preparation functions. The hot water tank always stores hot water, and it uses the most electric power when stationary. Therefore, energy saving initiatives are important.

Conventional hot water tanks were insulated only with foamed plastic. To promote energy saving, Fuji Electric used thermography to perform measurement and thermal analysis, and adopted vacuum heat insulating material that offers higher insulation performance. If the vacuum heat insulating material makes direct contact with the hot water tank, various problems could occur. For example, insulation performance could be reduced due to degradation over time or damage to the outer surface. In response, we have adopted a 3-layer heat insulating structure in which the insulating material is pinched from the inside and outside by foamed plastic (see Fig. 2). This reduces the annual power consumption of the hot water tank from 380 kWh/y (conventional models) to 325 kWh/y, a decrease of 14%.

5.2 Energy-saving ice maker

Ice makers are mechanisms that create and store ice. The ice maker compressor repeatedly starts and stops depending on the amount of ice remaining. After

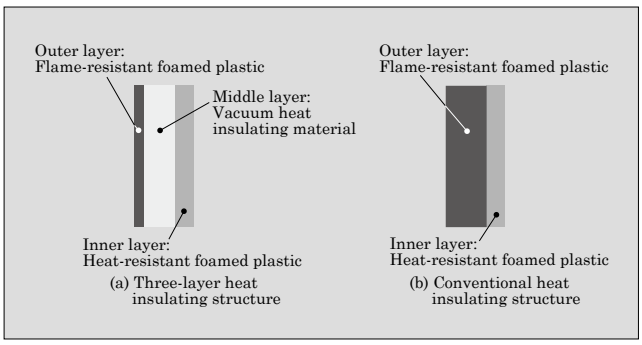


Fig.2 Hot water tank heat insulating structure

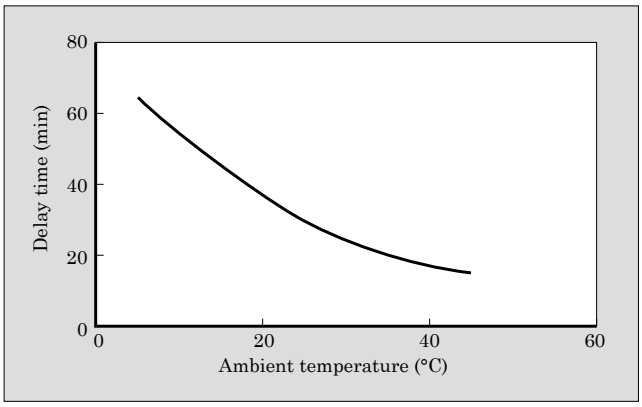


Fig.3 Ice maker compressor operation delay time

the compressor starts, ice cannot be created for 1 to 2 minutes as it takes this long for the refrigerant to begin circulating. In response, we designed the compressor to start less often, and reduced the amount of time spent merely circulating the refrigerant, not creating ice, thus resulting in more efficient ice making.

Demand for ice fluctuates greatly depending on the varying temperatures of the seasons. We have focused on this, and developed highly efficient control functionality that optimizes the amount of ice stored in the ice maker, as a parameter of the ambient temperature. An operation delay time is set in the compressor (see Fig. 3) to increase and decrease the amount of ice made in the summer and winter, respectively.

These improvements have reduced the annual power consumption of the ice maker by 25%.

6. The Most Advanced Preparation Technology in the Industry

6.1 "Shaking control" preparation technology

Cup-type vending machines prepare coffee using a cup mixing system, in which ingredients and hot water are stirred using a propeller in the cup. During propeller stirring, the position, rotating speed and time can be widely set according to ingredient characteristics such as granularity and viscosity. Furthermore, the machine comes with the cutting edge "shaking control" preparation technology that shakes the cup horizontally when stirring (see Fig. 4). This improves stirring efficiency allows for increased beverage variation, improves beverage quality and reduces selling times. Figure 5 indicates the comparison of beverage temperatures after they have been stirred for a certain period of time. This clearly shows that shaking control keeps beverage temperatures uniform in a short amount of time.

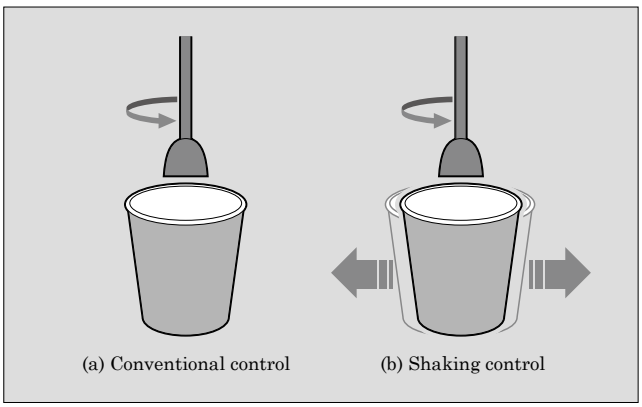


Fig.4 Cutting edge "shaking control" preparation technology

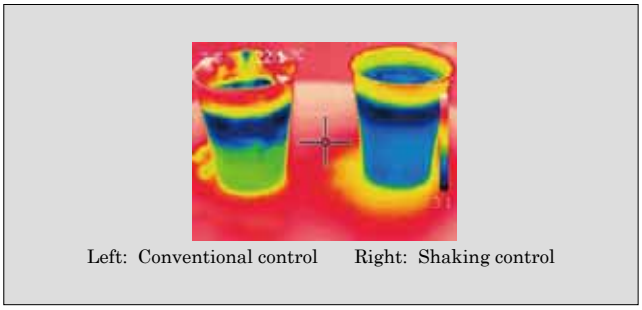


Fig.5 Beverage temperature comparison

6.2 Simple cap mixing sales system

The cup mixing system prepares the beverage in the cup each time a sale is made. In addition to being sanitary, this results in few parts that need to be cleaned.

Conventionally, all sales processes, including cup delivery, ingredient selection, coffee (hot water) selection, propeller preparation, and conveyance to the cup reception window, were performed via 2-axis (X and Y) operation, and required a large space.

In response, we have developed the industry's first horizontal uniaxial conveyance mechanism in order to save space. This mechanism is capable of performing all preparation processes on a single horizontal axis, as the preparation location and delivery window are shared (see Fig. 6 and Fig. 7).

With conventional machines, the beverages tend to splash when ice is dropped in the cup during preparation, making consumers feel that the cups and the delivery window are unsanitary. In order to resolve this issue, we have implemented a reduction in the speed at which ice is dropped into the cup, and designed a struc-

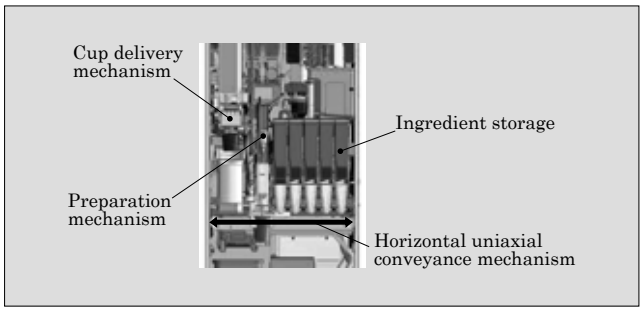


Fig.6 Sales process mechanism

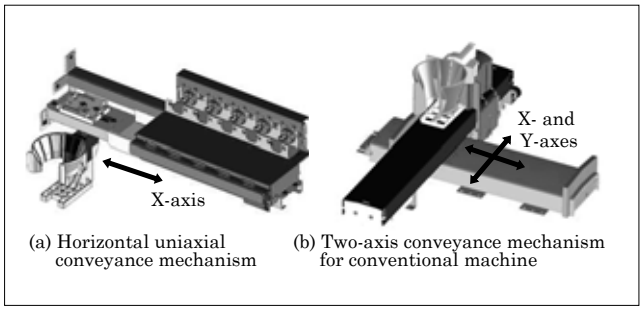


Fig.7 Sales process mechanism

ture where the ice is placed in the cup from directly overhead (see Fig. 8). This reduces beverage splashing.

We have also added a control that changes the timing at which ice is discharged for each beverage. For powdered beverages, we have added a control function that inserts ice after the ingredients have melted in a

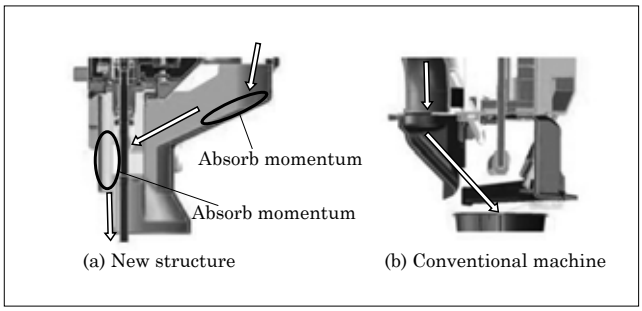


Fig.8 Reduced ice dropping speed

small amount of hot water, then adds more hot water. Adding ice to just a small amount of beverage stops the beverage from splashing outside. For regular beverages (black), we have added a control function that extracts coffee after first adding ice to the cup. These controls form a structure that minimizes beverage splashing outside the cup.

7. Postscript

This paper described the office-use ultra-compact cup-type vending machine “FJX10.” By continuing to seek further energy saving initiatives and improved taste, we will help to expand the cup-type vending machine market. We will continue to observe market needs and plan to continue to create cup-type vending machine products to satisfy consumers.

Cold Storage Container "Chilled Type D-BOX"

ONZUKA, Shojiro* ISHINO, Yuji* TOGASHI, Hajime*

ABSTRACT

In recent years, there has been increasing awareness concerning the need for food safety and security, and as a result, the food distribution industry has become more strictly required to manage the temperature of food products throughout all of the stages of the supply chain. Fuji Electric has developed the Cold Storage Container "Chilled Type D-BOX" to reduce the cost of distribution processes and completely meet the needs of managing the temperature of food products. The Chilled Type D-BOX is capable of keeping food products in the chilling temperature range for 5 hours without a power supply, even in environments with an ambient temperature of 32 °C. Furthermore, it can freeze the cold storage materials in 4 units simultaneously in 3 hours.

1. Introduction

In recent years, there has been increasing awareness concerning the need for food safety and security, and as a result, the food distribution industry has become more strictly required to manage the temperature of food products throughout all of the stages of the supply chain.

To meet the need to reduce initial and running costs while ensuring food safety and security with an integrated distribution system that thoroughly controls temperature, Fuji Electric has developed "Chilled Type D-BOX," a product that consists of a standalone-type accelerated cooling unit and "D-BOX" cold storage containers (see Fig. 1).

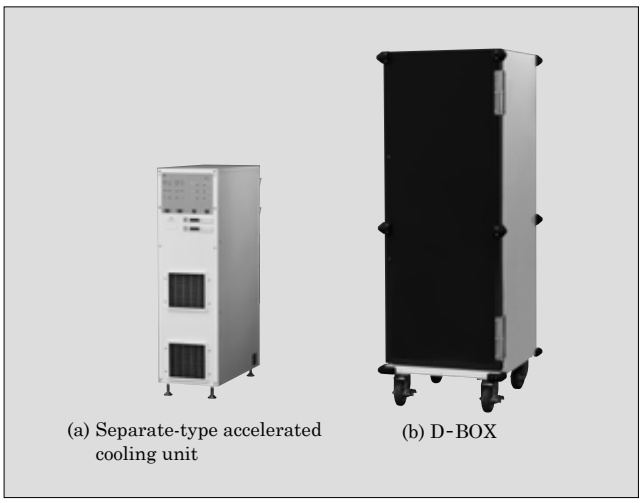


Fig.1 "Chilled Type D-BOX"

* Food & Beverage Distribution Business Group, Fuji Electric Co., Ltd.

2. Development Background

To ensure both the safety and quality of food during the food distribution process, products are transported in several types of trucks (such as chilled and refrigerated trucks) to keep each item at its ideal temperature. However, chronic driver shortages, difficulty ensuring vehicles and problems facing the industry such as dramatic fuel cost increases due to the inexpensive yen require that quick measures be taken.

In response, Fuji Electric continues to develop its "D-BOX Series" with 3 temperature ranges (frozen: −20 °C or lower; chilled: −5 °C to +5 °C; normal: 10 °C to 20 °C). This equipment seamlessly controls products at constant or low temperatures to maintain freshness and makes it possible to transport products in trucks kept at normal temperature, thus reducing initial distribution costs and bringing customers a revolution in how products are distributed. Among these, Chilled Type D-BOX makes it possible to store fresh food and other products in cold storage and maintain freshness.

3. Development Goals and Challenges

3.1 Overview of "Chilled Type D-BOX"

Chilled Type D-BOX is composed of a standalone-type accelerated cooling unit equipped with 2 refrigeration devices, and D-BOX cold storage containers that are characterized by their ability to keep food products cool for a long period of time without any power supply. Figure 2 demonstrates an implementation example.

Prior to implementing Chilled Type D-BOX, product temperatures were controlled for each of the following processes when transporting products in the chilled temperature range.

(a) Products are kept cool by loading them on pal-

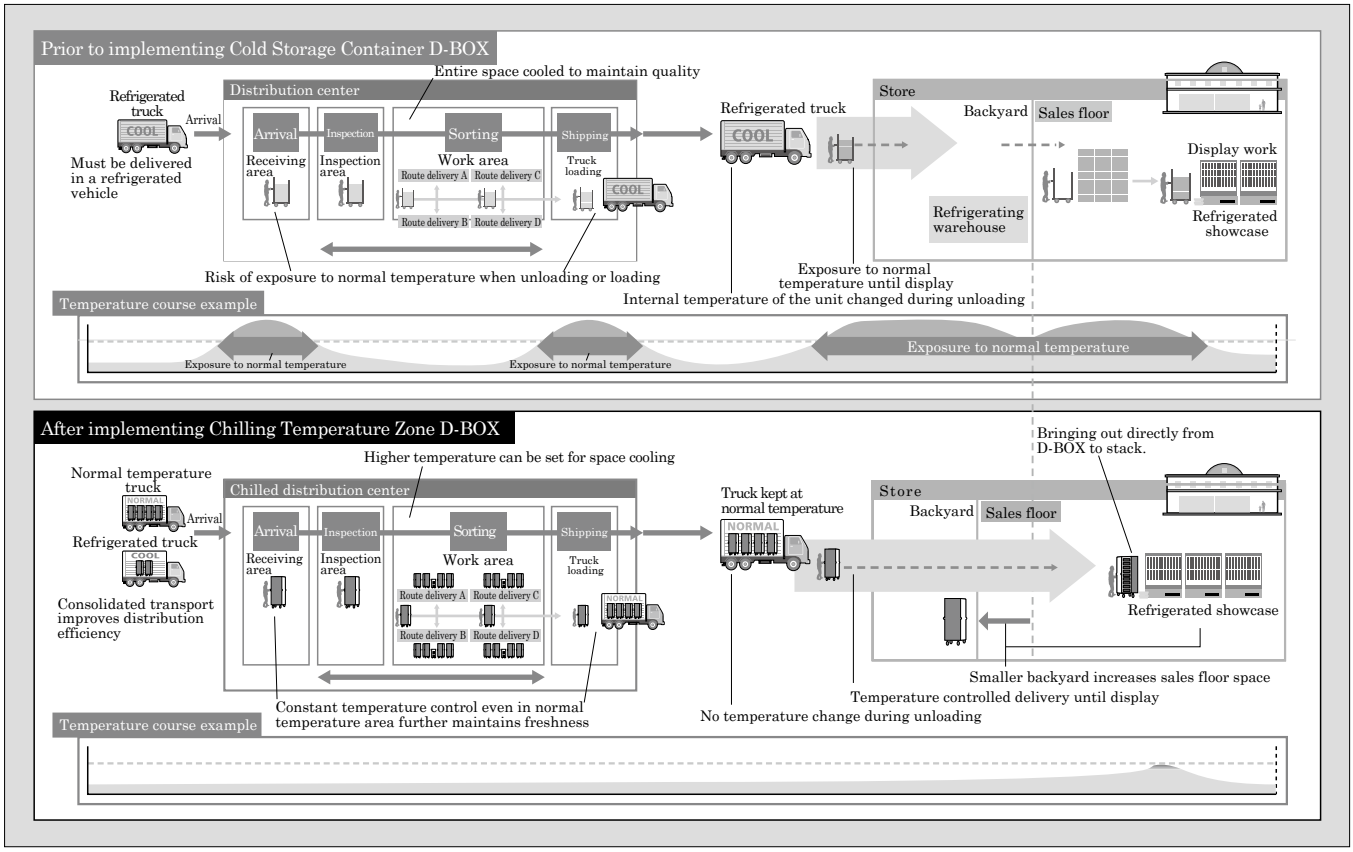


Fig.2 "Chilled Type D-BOX" implementation example

lets in a refrigerated truck

(b) The entire space of the distribution center is cooled for inspection and sorting

(c) Products are kept in a refrigerating warehouse from the point they are dropped off at stores to when they are displayed

However, products are taken and removed from cargo cars at the loading/unloading docks of the distribution center or in the store backyard, so there is a risk that products will be taken out of cold storage and exposed to normal temperatures. Furthermore, products could be exposed to normal temperatures for a longer period of time due to delivery truck arrival delays or worker mistakes, increasing the risk of reduced product quality.

Implementing Chilled Type D-BOX can eliminate the risk of products being exposed to normal temperatures during all processes, as products are constantly kept cool by the cold storage material inside the container. This also means that only the space used for sorting in the distribution center must be cooled, as it is possible to load those products together with processed food under normal-temperature control in trucks kept at normal temperature. There is also no need to install a refrigerating warehouse in store backyards. This can significantly contribute to reducing overall costs; for example, the space saved can be used to expand the sales floor.

Figure 3 shows the internal structure. Figure 4 demonstrates the D-BOX operation process. Table 1 lists the product specifications.

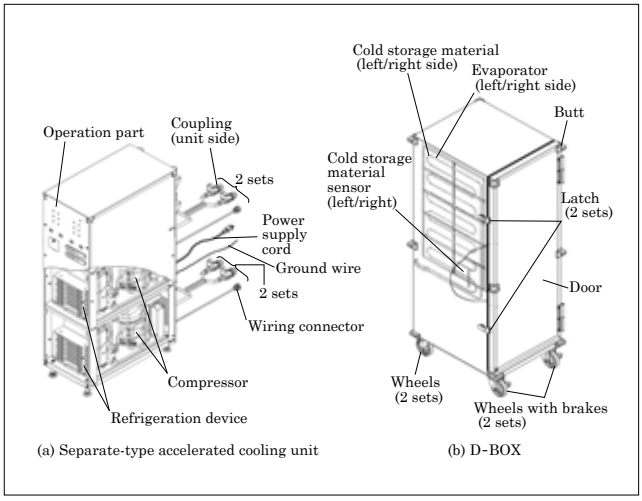


Fig.3 Internal structure

3.2 Long term cold storage performance

A market research showed that most products are distributed in the chilled temperature range (−5 °C to +5 °C). These results suggested that a performance capability of 5 hours of cold storage with an ambient temperature of 32 °C is required to distribute products in summer at the chilled temperature range in an integrated manner that covers the entire process from

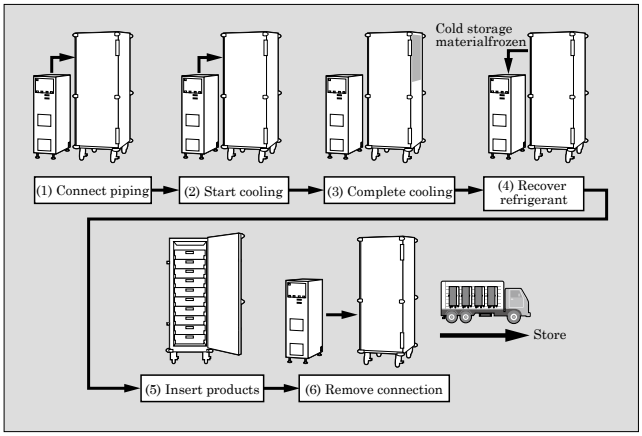


Fig.4 Operation process

Table 1 "Chilled Type D-BOX" specifications

Item		Specification
Standalone-type accelerated cooling unit	Model	DUNITAA1-15J
	Dimensions	W340×D678×H1,184 (mm)
	Mass	82 kg
	Power supply	Single-phase, 100 V, 15 A
	Refrigerant	R134a
	No. of refrigeration devices mounted	2 units
	No. of D-BOX units cooled simultaneously	4 units
	No. of D-BOX units that can be operated	16 units
D-BOX	Model	DBOXC1A11FC-111J
	Dimensions	W664×D793×H1,804 (mm)
	Usable internal dimensions	W469×D594×H1,488 (mm)
	Usable internal volume	415 L
	Cold storage temperature	−5 °C to +5 °C
	Cold storage time	5 hours
	Cooling time	3 hours
	Mass	105 kg
	Maximum loading capacity	250 kg
	Door	One door (270° opening angle)
	Wheels	Four free movement wheels (2 wheels with brakes)

product loading to truck transport, store backyard storage and product display.

3.3 Accelerated cooling system for cold storage materials

During busy periods, chilled distribution centers make a maximum of four deliveries per day. Deliveries took 3 to 4 hours per single cycle. In cases of repeated deliveries, in order to not hinder delivery schedules at centers, we designed a system that has an accelerated cooling capability of freezing cold storage materials in 3 hours and can completely cool four D-BOX units simultaneously with a single standalone-type accelerated cooling unit. This means that a single standalone-type accelerated cooling unit can be used to operate a maximum of 16 D-BOX units, four units operating four times a day. When adding containers in preparation for busy periods, customers can add only the number of D-BOX units needed for delivery, given that they have enough units that can be operated. This allows them to save equipment implementation costs.

3.4 Key points toward improving product transportation efficiency

Container dimensions and mass are extremely important aspects of truck transportation. In consideration of loading efficiency, we designed D-BOX with the dimensions and mass shown in the specifications listed in Table 1. The standalone-type accelerated cooling unit is also designed with the goal of reducing the weight of each D-BOX unit. A D-BOX unit was designed so that it has no noticeably uneven surfaces, and was given a highly heat-insulated, lightweight outer casing structure. Its dimensions allow for food crates (returnable plastic boxes) that contain products inside the unit to be efficiently loaded without any gaps. This improves both loading efficiency and operability.

4. Cold Storage Performance and Accelerated Cooling/Heat Insulating Technology

4.1 Cold storage performance

We utilized the heat insulating technology we have accumulated through developing vending machines, and combined it with newly developed technology that efficiently absorbs heat from the surface of the cold storage material to keep the unit cool, in order to give this product a highly heat-insulated and lightweight outer casing structure that is capable of keeping food products cool for a long period of time. It is particularly important to transport fresh food safely from chilled distribution centers to stores while also maintaining the freshness of said food. In order to confirm this, we measured changes in air temperature in the unit and dummy product temperature (see Fig. 5). In Fig. 5, 0 h is the moment the door was opened to insert the dummy product. The average air temperature in the unit increases between opening and closing the door.

Our measurements covered from the point products were loaded in the chilled distribution center, to when products were transported in a truck kept at normal temperature and stored in the store backyard. For loading work at the chilled distribution center, we opened the door, spent 2 minutes loading products at 0 °C under an ambient temperature of 15 °C, then closed the door. For storing products in the store backyard, we kept products cold for 5 hours at an ambient temperature of 32 °C.

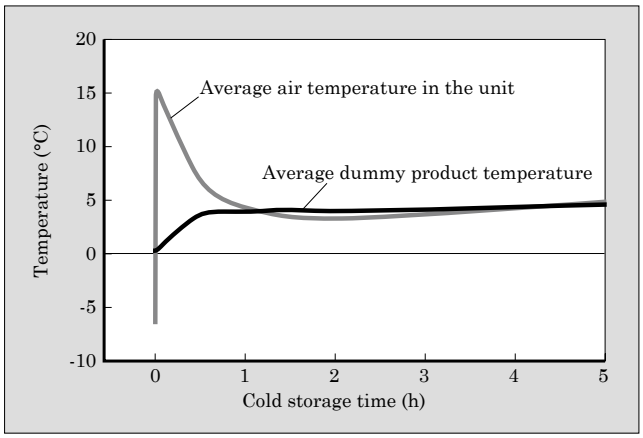


Fig.5 Changes in unit and dummy product temperature (ambient temperature of 32 °C)

Inside the D-BOX unit, product temperatures are kept at 5 °C or lower. When the door is opened and the air temperature in the unit rises to 15 °C, the temperature is cooled back down to 5 °C or less. During field testing conducted at customer chilled distribution centers, there was significantly less damage to the surfaces of products with a lot of moisture (such as slices of raw fish) caused by drying, because this product utilizes a cold storage system that does not use cooling fans inside the unit. The results proved the cold storage performance of this product, and demonstrated how effective it is in maintaining freshness for a long time.

4.2 Accelerated cooling/heat insulating technology for cold storage materials

In consideration of controlled temperature fluctuation in chilled distribution centers, we designed Chilled Type D-BOX to freeze the cold storage material for 3 hours at the maximum ambient temperature of 15 °C. Efficient cooling is required to see these results. As shown in Fig. 6 and Fig. 7, this product employs a direct cooling system where the heat exchanger makes direct contact with the cold storage material. It also uses vacuum heat insulating material, while combining the cold storage material and the heat exchanger

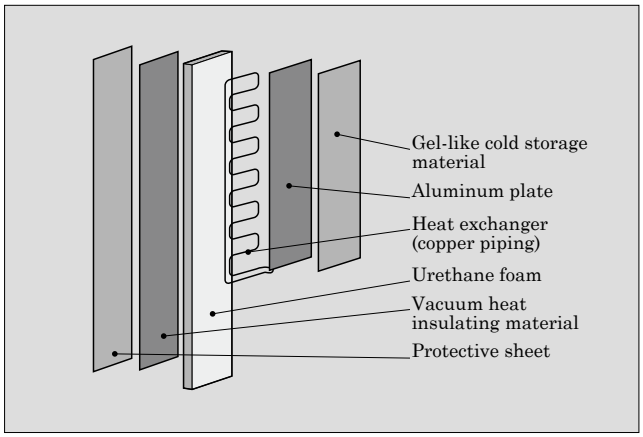


Fig.6 Structure of cold storage material cooling section

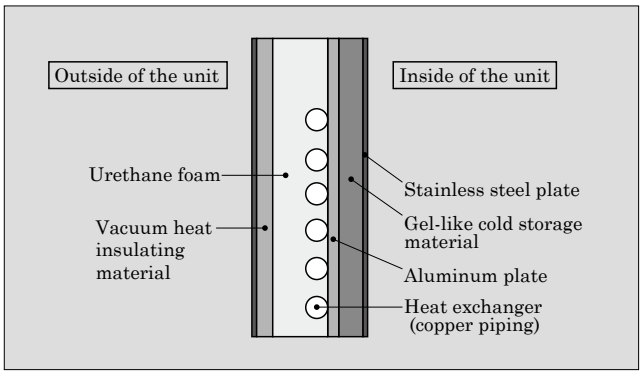


Fig.7 Cross-section structure

into a single urethane foam mold. This provides for stable contact between the cold storage material and heat exchanger over a wide area, and results in uniform cooling. We also set optimal foaming conditions to improve adhesion between the urethane foam and each component. This prevents corrosion caused by dew condensation or degradation of cold storage performance in the heat exchanger and cold storage material with a large ambient temperature difference.

For the cold storage material, serving as the core of cold storage, we used a gel substance with a very small difference between its melting and freezing points. It is also easy to handle if it should leak out due to damage. The cold storage material has a small difference between its melting and freezing points, so there is no need to cool it at a low temperature that could freeze fresh food. Sensible heat also prevents the temperature in the unit from falling immediately after the cold storage material is frozen. It is therefore effective in controlling product temperature, and the condensation temperature of the standalone-type accelerated cooling unit can be set high. For this reason, we adopted the widely popular refrigerant R134a. We also used a uniformly thin molding with a thickness of 10 mm for the cold storage material in order to improve its heat transfer performance, resulting in accelerated cooling.

5. Structure of Cooling Equipment

5.1 Standalone-type accelerated cooling unit

We adopted a separate type structure to save weight. Its design requirements included the ability for units to be installed and removed easily by users with no specialized knowledge, and high reliability that prevents refrigerant from leaking. In response, we developed a coupling on the connection to perform 2 separate actions: sealing the piping, and opening/blocking the refrigerant flow path during connection. This structure is able to significantly suppress refrigerant leakage when the flow path is opened during connection, as well as inhibit water or air from entering, which are issues with the single action system that is popular in the market. As a result, maintenance such as re-injecting refrigerant into the refrigeration device

Fig.8 Refrigerant piping connection

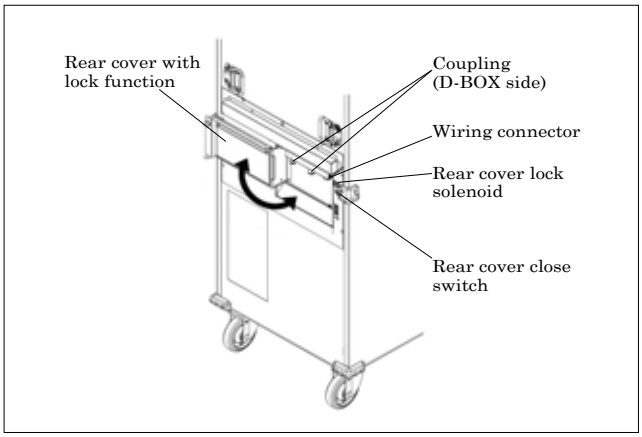


Fig.9 Structure of rear cover

is not required for 5 or more years. Furthermore, we use plastic hoses for the refrigerant piping to improve handling when attaching and detaching the coupling.

Finally, to prevent erroneous operation, the unit is equipped with a rear cover with a lock function on the piping connection so that piping cannot be tampered with during cooling operation. Figure 8 illustrates the refrigerant piping connection. Figure 9 shows the structure of the rear cover.

When the coupling is removed, the refrigerant recovery function causes the standalone-type accelerated cooling unit to automatically recover the refrigerant inside the refrigerant piping of the D-BOX unit. This unit employs a structure that releases the lock on the rear cover after refrigerant is recovered to the compressor, meaning that it can be operated by anyone.

5.2 Technology to cool multiple containers simultaneously by refrigeration device

The standalone-type accelerated cooling unit includes 2 refrigeration devices mounted on the upper and lower sections. A single refrigeration device can cool 2 D-BOX units. Therefore, a single accelerated cooling unit can cool a total of 4 D-BOX units. Figure 10 shows a cooling circuit diagram.

To control the amount of refrigerant, we developed

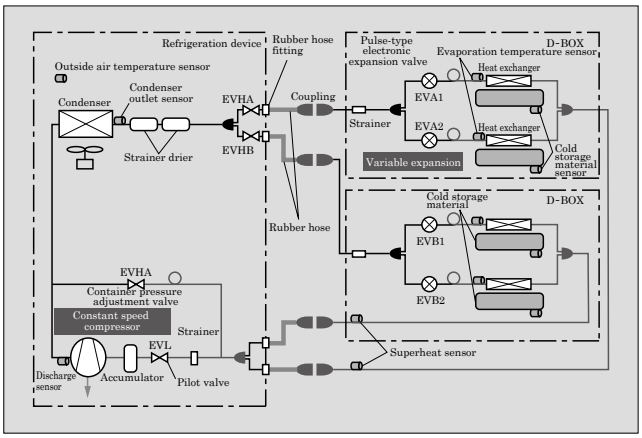


Fig.10 Cooling circuit diagram

a control that utilizes pulse-type electronic expansion valves. It determines the differing load fluctuations of the heat exchangers from the temperature data of each, and individually optimizes the amount of refrigerant circulation. This system can be used in any distribution scenario, and allows Chilled Type D-BOX to perform the following operations:

(a) Two-unit simultaneous cooling
(b) Single-unit independent cooling
(c) Time lag cooling where a second unit is connected while one unit is cooling

5.3 Antifreeze control

When cooling several heat exchangers with a single refrigeration device, the refrigerant circulation amount varies as the load balance changes, due to the effect of the installation environment and individual variations. The coupling, a part of the refrigerant piping, can freeze as a result, rendering it impossible to detach or attach.

For this reason, the refrigeration device incorporates coupling antifreeze control when cooling is complete, and optimizes the amount of refrigerant circulation during cooling. The temperatures of the cold storage material and piping are measured at fixed intervals. After cooling is complete, the pulse-type electronic expansion valves adjust the amount of refrigerant circulated and control the temperature of

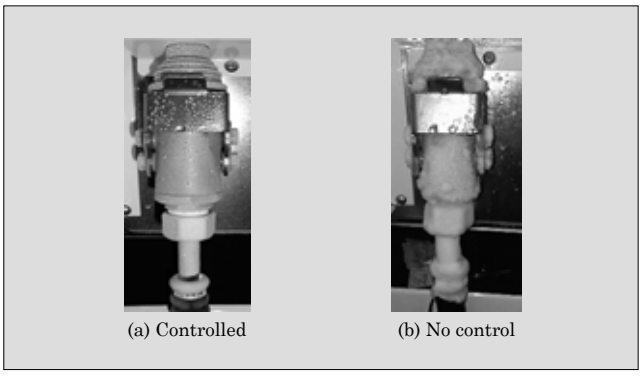


Fig.11 Effect of antifreeze control

the coupling. This keeps the cold storage material frozen, and prevents the low pressure side coupling and refrigerant piping from freezing. This prevents much frost from forming on the coupling, even under strict conditions such as long-term cooling in high humidity environments. Figure 11 demonstrates the effect of antifreeze control.

6. Postscript

This paper described the Cold Storage Container "Chilled Type D-BOX." In addition to adding "Frozen Type D-BOX" and "Normal Temperature Type D-BOX" to the D-BOX Series product lineup, Fuji Electric will continue to propose products to meet various distribution needs.

Drink Showcase Equipped with Inverter Freezer

MURABAYASHI, Kenji* KAGEYAMA, Toshiyuki* CHOU, Ikou*

ABSTRACT

In recent years, the impact of earthquakes has increased the demand for replacing products with more energy saving alternatives. Furthermore, convenience stores are also requiring open showcases that increase the product display area. Fuji Electric has developed an 8-shelf showcase that utilizes an inverter freezer and has a display area 1.57 times greater than previous products. The unit makes use of a new scroll compressor, while also adopting a new cooling system that utilizes segmented airflow, thus enabling the unit to achieve optimal inverter control that saves energy and stabilizes temperatures inside the showcase. We have also developed a mechanism that uses the evaporation fan to implement forced evaporation of drain water with the aim of saving energy and reducing the operation. The unit achieves a 67% reduction in power consumption per unit area.

1. Introduction

In recent years, the impact of earthquakes has raised the awareness of energy saving and increased the demand for replacing products with more energy-saving alternatives. In convenience stores, there is an increased demand for reduction of the operations for product display and cleaning in order to improve efficiency of store operations.

For meeting these market demands, Fuji Electric has developed an drink showcase equipped with inverter freezer. We are the first to achieve extensive energy savings with an 8-shelf drink showcase that has a display area 1.57 times greater than previous 6-shelf showcases.

2. Development Background

Convenience store customers have traditionally been mainly young people, but the customer base is expanding to include people living alone, the elderly and women in dual-income households. The expansion of the customer base and broadening of customer demands have led to the increase in the types of goods they offer. In addition, development of private-label products, which offer high profitability, is active in the convenience store industry and open showcases with increased product display areas are desired for efficiently displaying products in smaller store spaces than those of supermarkets. Furthermore, the advent of energy drinks – the market for which has rapidly grown in the last few years and is said reach a scale of 50 billion yen in FY2015 – has created a demand for increased display areas for nutritional drinks.

3. Development Goals and Challenges

Figure 1 shows the newly developed drink showcase equipped with inverter freezer. The goals of development are improved product display efficiency by increasing the product storage capacity, energy saving by utilizing an inverter freezer, and reduction of the operation by completely evaporating drain water.

For increasing the product storage capacity, we have expanded the front opening by increasing the height and lowering the front edge of the base of the unit and increased the capacity and product display area in the showcase by increasing the number of shelves. Expanding the front opening causes a significant increase in energy consumption because of the increased amount of external air infiltration. To address this problem, we fundamentally revised the conventional air curtain and developed a new cooling system that also utilizes “segmented airflow” produced by making a duct structure to channel cold air

Fig.1 Drink showcase equipped with inverter freezer

* Food & Beverage Distribution Business Group, Fuji Electric Co., Ltd.

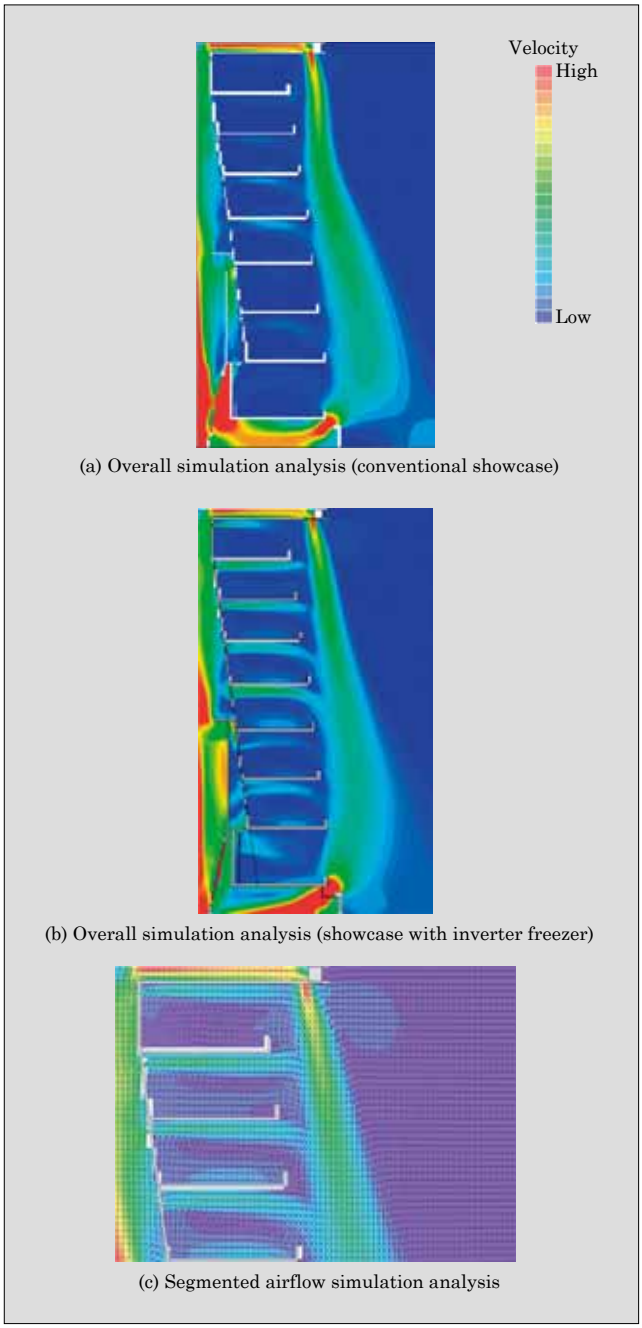
from the back to under the shelves. We also revised the conventional constant-speed operation of the installed freezer and developed an inverter-controlled system with a significant energy saving goal of reducing the amount of power consumption per unit capacity to a half or less. Another challenge was drain water. Conventionally, the drain water generated during defrosting was stored, which an employee had to drain out when the tank became full. With the aim of saving energy and reducing operation, we have worked to eliminate the evaporation heater from the drain water evaporation system and implement the ability to completely evaporate water without requiring a drain water tank.

4. Features

4.1 New cooling system

Figure 2 shows the result of flow velocity simulation analysis by using an optimization design support tool. In one common cooling system of conventional open showcases, the air curtain from the air outlet was used to shut off the external air and the cold air of the air curtain was drawn to individual shelves to use for cooling, which is supplemented by the air from the outlet on the back (see Fig. 2 (a)).

The newly developed system makes use of the cold air blowing from the back of a shelf, which is channeled through a duct made under the shelf above to allow even cooling of products. In this cooling system that utilizes segmented airflow, the cold air that flows under the shelves merges with the cold air of the air curtain. This reinforces the air curtain, allowing it to maintain a low temperature even near the lower shelves (see Fig. 2 (c)). Furthermore, an optimization design support tool has been used to extend the position of the canopy (cold air outlet projection at the top), adopt a honeycomb structure for the cold air outlet, and optimize the deck-integrated fence in front of the air inlet and air volume balance. This has achieved significant improvement in even temperature distribution in the showcase from 14 K to 7.1 K (see Fig. 2 (b)).



(a) Overall simulation analysis (conventional showcase)

(b) Overall simulation analysis (showcase with inverter freezer)

(c) Segmented airflow simulation analysis

Fig.2 Result of flow velocity simulation analysis by optimization design support tool

4.2 Inverter-controlled refrigeration system

Figure 3 shows the configuration of the freezer system, and Fig. 4 shows the structure of the freezer. Figure 5 shows the operation modes of the freezer.

The conventional constant-speed operation control of a freezer maintains the temperature in the showcase within a certain range by turning the freezer on and off, as shown in Fig. 5 (a). On-off switching occurs frequently and the inrush current that flows when the freezer is turned on increases the amount of power consumption. The on-off operation also causes hunting, or oscillation of the air temperature in the showcase, which increases the range of temperature distribution, making it difficult to stabilize the temperature.

To address this problem, we have adopted a new scroll compressor and developed optimal inverter control that saves energy and stabilizes temperatures inside the showcase, as shown in Fig. 5 (b). This control minimizes fluctuation of the temperature at the showcase air outlet detected with a temperature control sensor and allows to settle in the targeted air temperature promptly.

Specifically, when the temperature in the showcase rises abnormally, called pull down, during operations such as defrosting, the compressor operates at a constant high speed to rapidly lower the increased temperature in the showcase. When the temperature at the air outlet has reached the target, PID control is ap-

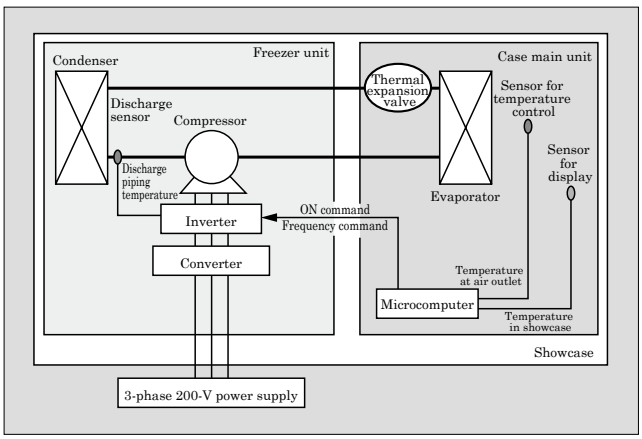


Fig.3 Feezer system configuration

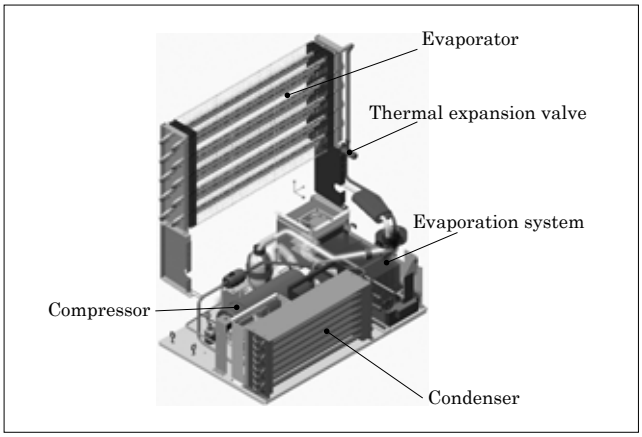


Fig.4 Freezer structure

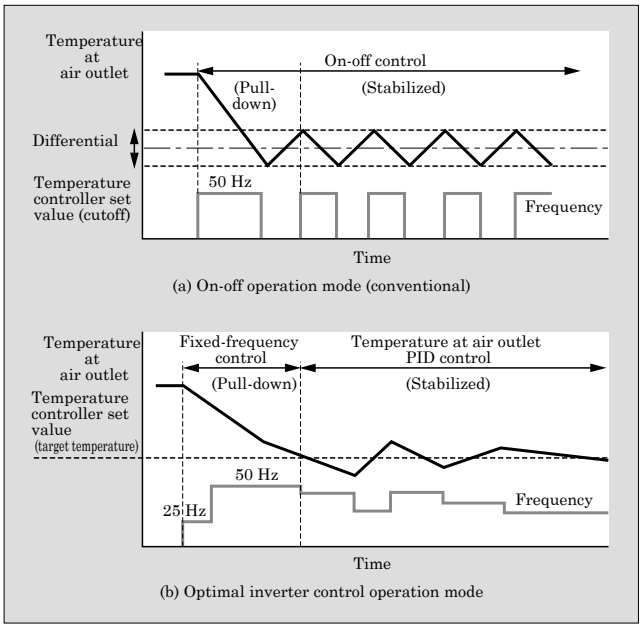


Fig.5 Freezer operation modes

plied to control the rotational speed of the compressor so that the temperature at the air outlet converges to the target temperature.

This inverter control has achieved a reduction of the amount of power consumption of the freezer from the conventional 16 kWh/d to 9.2 kWh/d, or by 42.5%, in operation under the conditions of 27 °C and 70%RH in the summertime. In addition, the amplitude of the temperature of the refrigerant discharge piping has decreased from the conventional 4 K to within 1 K, contributing to energy saving and stabilization of the temperature in the showcase.

4.3 Drain water evaporation system

Even though drink showcases are shielded with air curtains, they take in external air while cooling, which generates a large amount of drain water. Figure 6 shows the drain water evaporation system. Conventional showcases had primary and secondary evaporating dishes. The primary evaporating dish uses the heat of the evaporator coil on the cooling unit to achieve evaporation. The secondary evaporating dish uses an exclusive evaporation heater and a drain tank. This causes the heater to consume 6.9 kWh/d of electric power. With the newly developed showcase, the heater was eliminated for saving energy and the drain tank was also eliminated to reduce water draining operation by an employee. The goal was to achieve complete evaporation under the conditions of 27 °C and 70%RH in the summertime using forced evaporation by means of the evaporation fan.

(1) Structure of the evaporation system

The amount of evaporation is proportional to the air volume and the surface area of evaporation, and is also greatly influenced by the temperature (see Fig. 7).

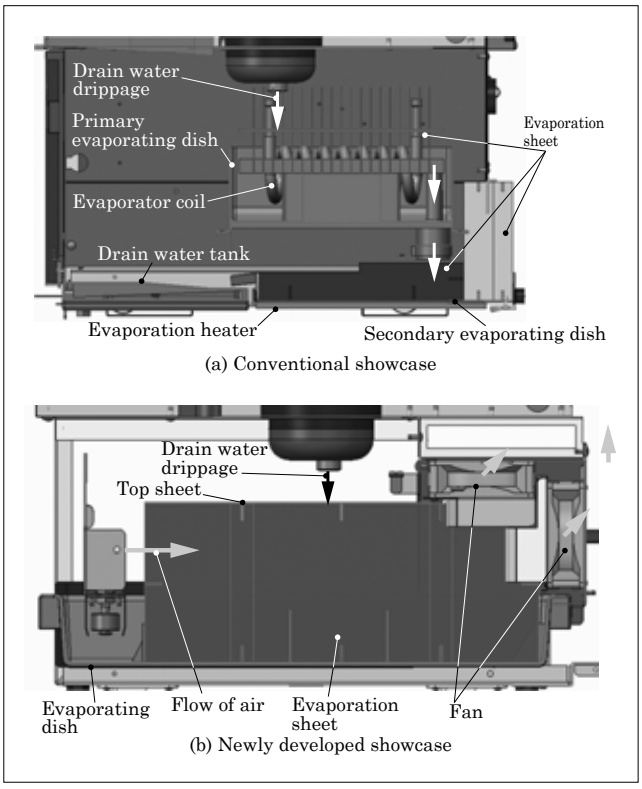


Fig.6 Drain water evaporation system

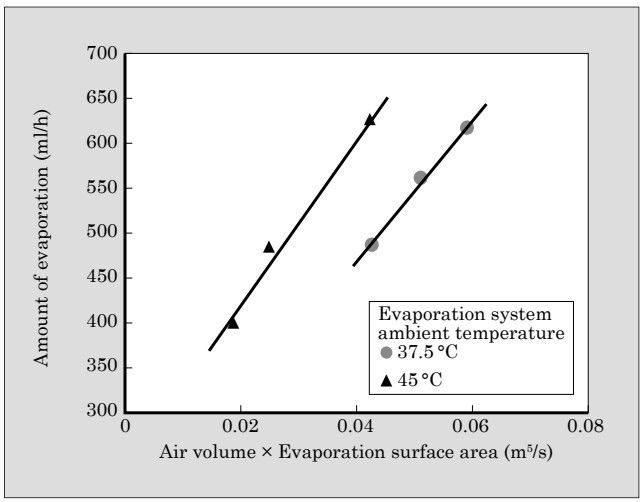


Fig.7 Amount of evaporation vs. air volume, evaporation surface area and temperature (experimental results)

Placing evaporation sheets on the fan air outlet side increases the effective air volume and in turn the amount of evaporation. However, in order to make it possible to remove the evaporating dish and exhaust the evaporated moist air by the heat of the cooling unit from the evaporation system to the back of the drink showcase, we have placed the fans behind the evaporation sheets as shown in Fig. 6 (b).

To increase the volume of air that passes through the evaporation sheet within a limited space, we have used 2 fans and determined the optimum arrangement of the evaporation sheets and fans by using airflow analysis (see Fig. 8).

(2) Improvement of evaporation capacity of evaporation sheets

With the conventional evaporation sheets, the water collected in a dish was simply absorbed by a vertically stretched evaporation sheet, which left the upper part of the sheet dry, and evaporation capacity was not being fully utilized. To address this problem, a top sheet has been added as shown in Fig. 6 (b) so that the drain water drippage spreads across from this top sheet, which is horizontally stretched. This has made the side and top sheets form a duct structure, which successfully allows the fan air to be carried through the entire span of the sheets. In addition, the water retention effect of the top sheet and the effect of the duct structure have improved evaporation efficiency by 80%.

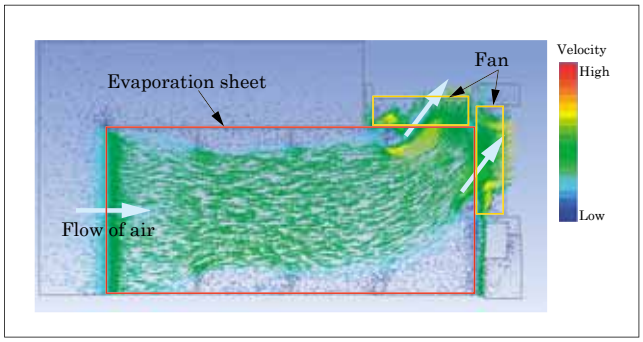


Fig.8 Airflow analysis result

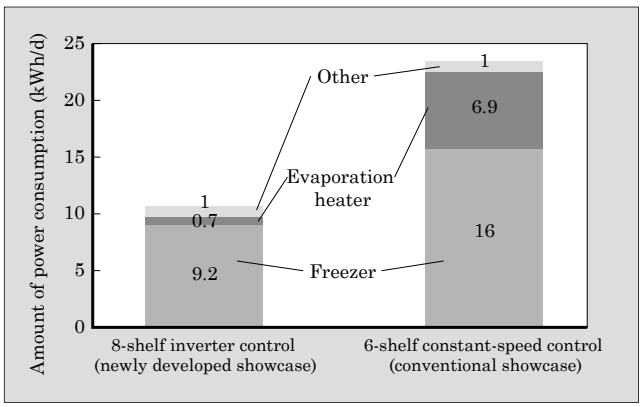


Fig.9 Comparison of amount of power consumption

Table 1 Performance comparison

Item	8-shelf inverter control (newly developed showcase)	6-shelf constant-speed control (conventional showcase)
Showcase capacity (L)	240	175
Average air temperature (°C)	7.6	9.3
Amount of power consumption (kWh/d)	10.9	23.9
Amount of power consumption per unit capacity (kWh/d/L)	0.045	0.137
Display area (m²)	1.57	1.00

The improved evaporation capacity of the evaporation sheets has made complete evaporation without a heater, and the amount of power consumption has been reduced by approximately 90% from 6.9 kWh/d with conventional showcases to 0.7 kWh/d.

4.4 Performance

By making use of the new technologies described above, we have achieved a significant reduction in the amount of power consumption per unit capacity of 67%, which exceeds the goal of 50%. Figure 9 shows a comparison of the amount of power consumption with conventional showcases, and Table 1 shows a comparison of performance.

5. Postscript

This paper described the drink showcase equipped with inverter freezer. This newly developed product has been highly rated by customers for its improved product display efficiency, energy saving and reduced operations. However, the demands of the convenience store industry are rapidly changing by the moment. We will continue to actively promote the development of new products that anticipate the needs of the market and lead the industry.

Energy Saving Control System for Freezing-Refrigerating Warehouse

KATO, Hiroshi* SHIRAKI, Takashi ‡

ABSTRACT

Freezing-refrigerating warehouses, which are designed for storing and sorting products in food distribution processes, are being required to be more energy efficient due to increasing electricity costs. Fuji Electric has developed an energy saving control system for centrally controlled freezing-refrigerating warehouses that optimizes the operation of the freezing-refrigerating equipment (refrigeration unit, unit cooler) inside warehouses while also making it possible to carry out efficient operation control. It has been confirmed that yearly power consumption in warehouses can be reduced by 12.3% through the adoption of enhancements such as optimized control for the unit cooler and pressure control for the low-pressure side of the refrigerator unit utilizing a unique algorithm for responding to load conditions inside the warehouse.

1. Introduction

In recent years, freezing-refrigerating warehouses have been increasingly required to contribute to energy saving and facilitate energy visualization in accordance with the provisions of the "Act on the Rational Use of Energy" (Energy Saving Act). Furthermore, warehouse operators have been increasingly requiring centrally controlled systems that come equipped with a temperature management system for ensuring the level of food safety demanded by consumers, as well as energy saving functions to support suppression of operation costs in equipment.

In order to meet these market needs, Fuji Electric has developed an energy saving control system for freezing-refrigerating warehouses based on the "ECOMAX Controller," which is an industry-proven controller designed for stores.

2. Development Background

Freezing-refrigerating warehouses are utilized for storing frozen and refrigerated food products, as well as in the sorting work required in shipping. In most cases, they can continue to be used and operated for many years even after a 20-year amortization period, thus providing them with a reputation for having a substantial life cycle and extremely long investment payback period (see Fig. 1).

However, in recent years, freezing-refrigerating warehouses that are larger in size and more integrated have been increasingly penetrating the market in order to improve the efficiency of distribution networks.

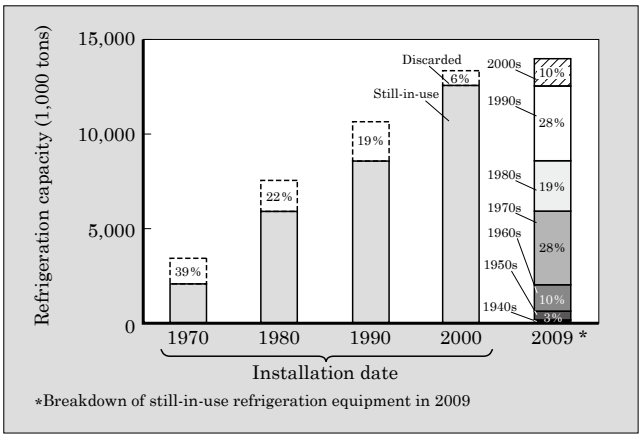


Fig.1 Breakdown of installation dates for freezing-refrigerating warehouse equipment

In addition, there has been an increasing number of facility upgrades for freezing-refrigerating warehouses to facilitate compliance with regulations for preventing global warming, including switching from fluorocarbon refrigerants to more environmentally friendly refrigerants .

Moreover, the rise in electricity rates has gradually increased the financial burden of operators, and as a result, there has been a greater demand for energy saving solutions.

In order to improve energy saving, freezing-refrigerating warehouses need to be equipped with the latest equipment and energy measuring equipment, and thus require a somewhat sizable investment. However, in consideration of the fact that operators need to suppress investment costs as much as possible, we have pursued the development of a control system that contributes to energy savings and increased efficiency in energy visualization, while not requiring a hefty investment.

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3. Development Goals and Challenges

Since system complexity is directly related to increased costs, we place high importance on adopting a relatively simple configuration for the freezing-refrigerating warehouse. Therefore, we need a simple system to implement energy savings without requiring many sensing rather than a supervisory control and data acquisition (SCADA) system.

In developing the system, we formulated the system requirements to enable comprehensive management and energy saving control of the freezing-refrigerating warehouse as follows:

(1) It can be introduced easily in a low-cost under various layouts and operating conditions. To achieve this, the function of visualizing energy saving effect, power consumption and other monitoring data should be developed for Fuji Electric's facility equipment management controller for warehouses.

(2) It can monitor temperatures and operating status inside each warehouse in real time, and its system settings can be changed easily depending on the operation.

(3) It can energy saving control according to the operating conditions of equipment installed in the warehouse

(4) It has demand control functions, such as power consumption management and peak-cut operations.

4. System Overview and Features

Figure 2 shows the configuration of the system. The "ECOMAX Controller" is the main component of the system. It collects operation data from each piece of equipment and provides simple functions for carrying out control based on the data. There are many different types of layouts inside of warehouses to accommodate application needs, and the system facilitates efficient operation by enabling operation and operation management of all pieces of equipment from the office.

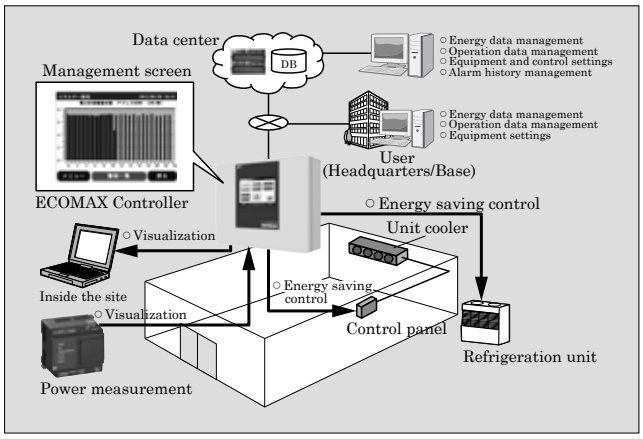

Fig.2 System configuration

(1) Status management and settings

The controller is mounted with a built-in color touchscreen that is highly visible and easy to use. In addition, users can connect to the Internet to perform remote management and setting configuration.

(2) Energy saving control

In order to improve operation efficiency in the refrigeration unit and unit cooler, which are the main components of freezing-refrigerating equipment, the system performs pressure control of the low-pressure side of the refrigerator unit, optimized control of the unit cooler, and load leveling control, thus enabling it to achieve yearly energy savings of 12.3% compared with conventional systems that do not implement control.

(3) Energy management control

The system makes it possible to display graphs to view the operation data and power consumption of equipment. Furthermore, it is possible to configure target values (maximum power) with allowance rates for cumulative power consumption in 30-minute intervals in order to suppress the maximum demand of power. In addition, demand control makes it possible to determine the likelihood of exceeding target values based on power usage estimations, and the unit enables power suppression control and automatic restoration control, while also preventing excessive suppression control of power.

5. Management Functions

The system broadly divides its functions into 2 types, which include energy management functions and status management functions for the freezing-refrigerating equipment. The functions include local management in which controller changes the settings according to changes in operating conditions, and center monitoring that provides information history via data server and correlation analysis between temperature transitions and energy.

(a) Status management functions
- ○ Internal temperature management
- ○ Operating status monitoring
- ○ Cooling management (temperature-controlled shift schedule)
- ○ Defrosting management (defrosting schedule)

(b) Energy management functions
- ○ Energy monitoring

(c) Data collection

(d) Alarm monitoring

Figure 3 shows an overview of the controller management screen configuration.

(1) Local management

As a means of local management, it is possible to adjust the settings for the temperature inside the warehouse and configure a schedule for performing defrosting operations for the unit cooler from the control-

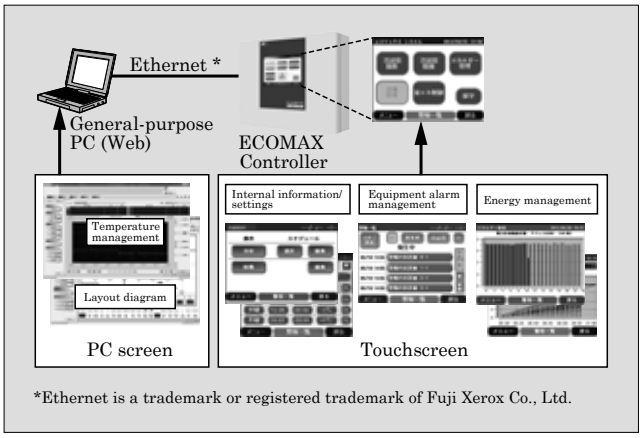

Fig.3 Overview of the controller management screen configuration

ler-mounted touchscreen all at once. Furthermore, the unit has other features such as a function for raising an alarm when equipment or temperature abnormality is detected based on temperature information in the warehouse. When an alarm is raised, immediately the display is switched to the operation information monitoring screen for the relevant piece of equipment, and notification is made via an alarm buzzer or email.

The unit can also provide visualization of energy usage covering a period of up to 2 days, providing equipment administrators with an improved day-to-day management awareness as they make comparisons with the previous day.

(2) Center Monitoring

This system comes with built-in web server functions to enable users to manage detailed information from remotely located computers.

Furthermore, data regarding the operating conditions of facility equipment and the usage conditions of energy stored by the system's controller can be acquired via network communication. Users can easily implement centralized management of multiple sites from remote locations such as the company headquarters or other offices, while even performing comparative analysis between locations based on energy indicators1.

6. Control Functions

This system comes equipped with operating control functions for the refrigeration unit and unit cooler, which are the main components of the freezing-refrigerating equipment. Acquiring operation information for the unit cooler from the controlgear, the controller sends control orders to the refrigeration unit. Control functions include an energy saving control function and a demand control function.

Furthermore, we are currently developing load fluctuation control for implementing energy savings and maintaining a stable temperature inside warehouses to respond to sudden cooling load changes that occur when opening and closing doors during loading and shipping of products. We plan to release this function during FY2016.

6.1 Energy saving control functions

Energy saving control is conducted in combination with the following control functions.

(1) Pressure control function for the low-pressure side of the refrigerator unit

Pressure control for the low-pressure side of the refrigeration unit is capable of achieving energy savings by controlling the output (low-pressure side) of the refrigeration unit in response to heat loads inside the warehouse in order to harmonize heat loads with output.

Specifically, the operating conditions (electromagnetic valve on-off information) of the unit cooler installed in the warehouse are reported to the controller, which then performs calculations based on the operating conditions in order to control the refrigeration unit so that it operates at the minimum required refrigeration capacity. By doing this, it is possible to determine the total required refrigeration capacity (demand) and perform operation while maintaining an appropriate refrigeration capacity (supply) by controlling the pressure of the refrigeration unit, thus contributing to the suppression of excessive power consumption.

A basic overview of the algorithm is given in the block diagram of Fig. 4. Determination regarding the operating conditions of the unit cooler is made based on the electromagnetic valve on-off information (electromagnetic valve operation information) for controlling the flow of refrigerant used in cooling the heat exchanger in the unit cooler. When the electromagnetic valve on (cooling on) time is longer than the maximum setting value, it is determined that "the load of the unit cooler is above the refrigeration capacity," and when the electromagnetic valve off (cooling off) time is longer than the minimum setting value, it is determined that "the load of the unit cooler is below the refrigeration capacity." When it is between these 2 setting values, it is determined that "the load of the unit cooler and the

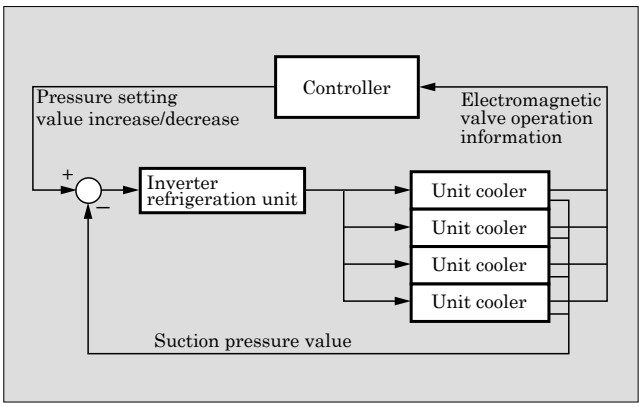

Fig.4 Basic block diagram of pressure control algorithm for the low-pressure side of the refrigeration unit

refrigeration capacity are nearly balanced."

With regard to the refrigeration unit for inverter control, frequency control is conducted to ensure that the suction pressure value of the refrigerant is equivalent to the pressure setting value. When the pressure setting value is raised, the refrigeration capacity and power consumption drop, but when it is lowered, the refrigeration capacity and power consumption increase. As a result, when it is determined that even one of the multiple unit cooler loads suffers from insufficient refrigeration capacity, the pressure setting value is lowered to increase refrigeration capacity. On the other hand, when it is determined that the refrigeration capacity for all of the unit coolers is too high, the pressure setting value is lowered to decrease the refrigeration capacity. Finally, when it is determined that the refrigeration capacity is neither too high nor too low, control of the pressure setting value is implemented appropriately.

The utilization of the above algorithm achieves energy savings and ensures that the refrigeration capacity for multiple unit coolers is always optimally maintained.

(2) Unit cooler optimal control functions

Unit cooler optimal control contributes to energy savings by optimally controlling the activity of the unit cooler based on the cooling state.

Wasteful cooling operations can be suppressed by adjusting higher (setback) the setting temperature during time periods when the cooling load is low. Automatic operation can also be performed by configuring a weekly schedule to set time periods for performing the setback operation or periods when there are significant temperature changes.

Furthermore, energy loss related to unit cooler fan operations can be reduced by optimizing the operation of the fan when cooling loads are low.

(3) Load leveling control functions

In typical freezing-refrigerating warehouses, a single warehouse is equipped with multiple unit coolers and one temperature sensor. Based on the measured temperature, thermo operation (electromagnetic valve on-off control) is performed to maintain the target temperature.

This type of configuration faces the following challenges:

(a) Since all of the unit coolers implement thermo operation with the same behavior, it is difficult to maintain a balanced temperature inside the warehouse when there is diversity in cooling loads.

(b) Stable cooling cannot be performed when there is large fluctuation in refrigeration unit loads.

(c) During the winter when loads are relatively low, frequent starting/stopping operations by the electromagnetic valve on-off on the refrigeration unit generates wasteful startup power.

Load leveling control counters these challenges by utilizing a temperature sensor installed in each unit cooler, as shown in Fig. 5, to calculate the appropriate cooling load as required for each unit cooler, while also correcting the electromagnetic valve on-off timing of each unit cooler to enable thermo operation at a constant refrigeration unit load. As a result, the refrigeration unit can be operated with stability and high efficiency.

Moreover, stable operation for the refrigeration unit is also effective in suppressing unnecessary starting and stopping.

By combining load leveling control with the above mentioned pressure control for the low-pressure side of the refrigeration unit, it is possible to stabilize both the refrigeration unit side and the cooling load side to achieve a high energy saving effect.

6.2 Demand control functions

Demand control functions provide monitoring and controlling the power consumption of equipment to ensure that power consumption for the entire monitored warehouse does not exceed its target value. The demand control in this system has the following features with regard to its control method.:

(1) A method for determining if the target power value has been exceeded

In conventional demand control systems, the function for determining whether power consumption would exceed the target power value made predictions simply based on power consumption data per 30-minute interval. However, the current system makes determination of excessive power consumption by means of an upper-limit power value with an allowance rate for power consumption in 30-minute intervals. As a result, this method of determination prevents excessive suppression control when there are sharp increases or decreases in power consumption due to variation in

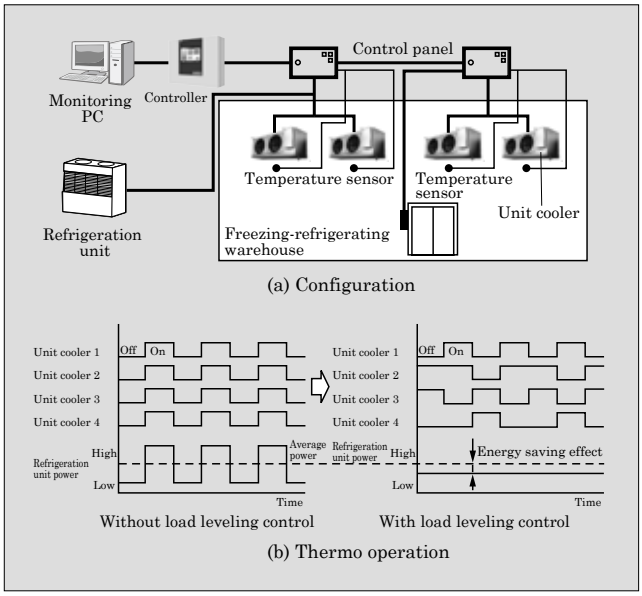

Fig.5 Configuration for load leveling control

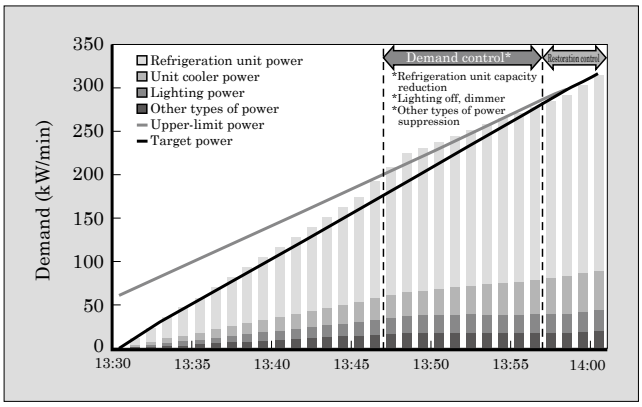

Fig.6 Demand control

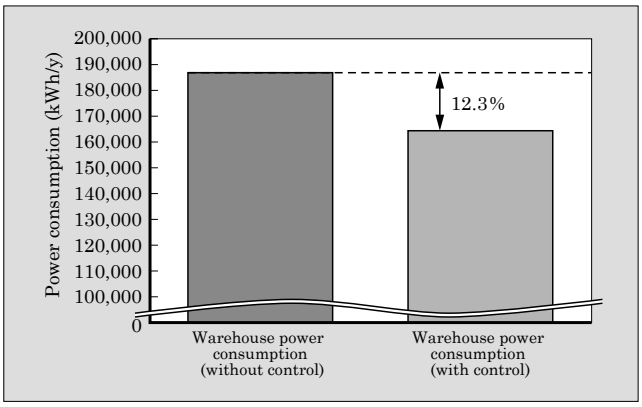

Fig.7 Energy saving verification and evaluation results

measurement values or sudden temporary changes in power consumption.

(2) A method for implementing consumption suppression control and restoration control

As shown in Fig. 6, when it is likely that power consumption will exceed the target power value based on a determination of exceeding the target value, the applicable equipment is sequentially controlled so as to decrease the power consumption in accordance with the previously established control object table in the 30-minute interval range, and thus perform suppression control of the power consumption.

Conventionally, restoration in typical demand control systems was often done manually. In this system, when an appropriate allowance is secured with the power consumption dropping below the target power value, control is implemented to restore the equipment sequentially to the states they were in before the excessive consumption occurred. The control object table, therefore, consists of data such as the identity of the applicable equipment, priority order, controllable range, and state before and after the control. By implementing the restoration automatically, this demand control system is not only applicable to power consumption peak-cut operations during the summer, but also makes it possible to implement operation as an energy saving entity by purposely setting target power value low.

7. Verification and Evaluation

We verified the energy saving control performance during the summer and winter in Fuji Electric's experiment-use freezing-refrigerating warehouse environment. The results verified that the system enables yearly energy savings of 12.3% (see Fig. 7). The amount of power consumption in Fig. 7 represents the combined effect of the pressure control for the low-pressure side of the refrigeration unit, optimal control of the unit cooler fan, and load leveling control.

8. Postscript

Along with the increasing number of upgrade projects for freezing-refrigerating warehouses, there has been a consistent need for energy savings and streamlining of work processes. In addition, the energy sector has been seeing a greater number of subsidized projects and joint development projects. Fuji Electric will continue its efforts to spread energy technology to Japanese and global markets by further developing energy saving functions and strengthening management and control features.

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Product Dispensing Mechanism for Vending Machines for Global Market

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ABSTRACT

The expansion and popularization of beverage vending machines in markets outside Japan has required stable power supply voltage that is not affected by different power supply voltages and unstable power conditions in some areas. To comply with the law and regulations without being affected by power conditions, Fuji Electric has adopted a low DC voltage power supply for the product-dispensing mechanism. It can supply sufficient drive energy at a low voltage by utilizing the configuration that combines a DC gear motor with a cam-linkage mechanism for the drive source used in the product-dispensing mechanism. Furthermore, we have greatly reduced the number of purchase issues that arise during the vending cycle by developing a sold-out detection structure compatible with various product shapes, as well as a malfunction detection function with detection switches.

1. Introduction

Although beverage vending machines have spread widely throughout Japan with approximately 2.56 million machines installed, these machines are on the cusp of widespread proliferation overseas. Expansion to the overseas market will contribute significantly to the vending machine sector in the future.

Due to the unstable power conditions and power supply voltage differences in each region, in expanding overseas it is necessary to use high-capacity transformers and other such devices to stabilize power supply voltage by raising and lowering voltages. It is also necessary to adhere to standards defined by the International Electrotechnical Commission (IEC). A policy to revise paragraph 2 of the "Electrical Appliances and Material Safety Act" ordinance in 2016 has been suggested in order to comply with IEC standards in Japan. To comply with laws and regulations without being affected by power conditions, Fuji Electric has started developing low voltage DC load devices. This paper describes our global efforts to develop a low voltage DC product-dispensing mechanism (vending mechanisms) ahead of other companies.

2. Development Background

Vending machines store products at ideal temperatures for drinking, and dispense and sell products selected by purchasers. Vending machines are composed of a variety of parts, such as the housing, freely opening/closing door, the vending unit that stores and dispenses products and the cooling/heating unit that heats and cools products (see Fig. 1). The vending unit is composed of a rack in which products are replenished and stacked on their side in each lane (column), and a mechanism installed on the lowest part of the rack that receives vending signals and electrically drives the vending mechanism to dispense products (see Fig. 2).

Figure 3 shows how the vending mechanism works.

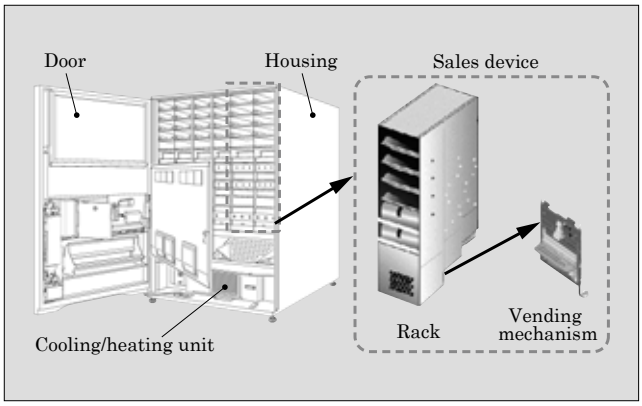

Fig.1 Vending machine product structure

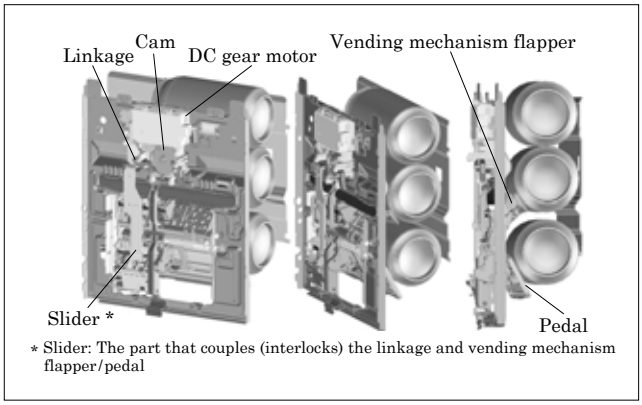

Fig.2 Vending mechanism

* Food & Beverage Distribution Business Group, Fuji Electric Co., Ltd.

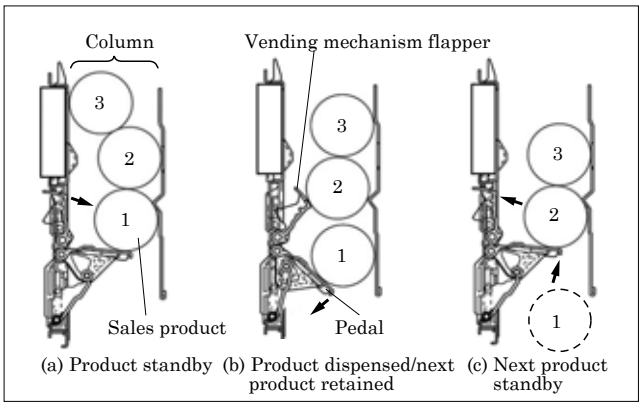

Fig.3 Vending mechanism operation

A number of products are stacked up vertically. Among them, only the product at the bottom is reliably sold, with an average load of approximately 5 kg exerted. For this reason, the vending mechanism is required to have a drive performance capable of reliably and quickly operating components such as the vending mechanism, flapper and pedal. AC solenoids that have been used as drive sources conventionally have a comparatively long operation stroke, making it easy to ensure the starting torque, holding torque and required operation speed. When an AC solenoid is used, however, high-voltage wiring is installed to support commercial power supplies such as 100 V AC in the mechanism, and this requires an insulation structure that complies with IEC standards. If the drive source of a vending mechanism that supports low voltage direct current can be achieved, an insulation structure that supports high voltage will no longer be required. Furthermore, there would be no need to prepare drive sources for commercial power supplies with differing voltages in each country and region.

3. Development Goals and Challenges

3.1 Ensuring of drive energy while changing to low voltage DC

A high direct current voltage of approximately 80 V DC is required for a DC solenoid to simply ensure the same performance as a 100 V AC solenoid. However, a new power supply will not need to be prepared if sufficient drive energy can be ensured by using a low voltage 24 V DC power supply equipped to drive the control system of a vending machine.

3.2 Sold-out detection that is not affected by product shape

Conventionally, actual machine testing was carried out to confirm whether products with various shapes could be sold, according to the guidelines established by each customer in Japan. However, as we expand overseas, it would be physically impossible to carry out actual machine testing on all products. Additionally, conventional vending mechanisms detect sold-out products by shape; thus, kinds of vending products have to be confined. Ensuring sold-out detection performance even for uncertain product shapes and expanding the range of products that can be sold is one challenge in expanding overseas.

3.3 Jammed product detection

We have implemented a variety of mechanical measures to prevent products from getting jammed to ensure that products can continue to be dispensed from the vending unit. However, actual vending machines handle products of varying shapes, and there are nevertheless cases where products get jammed and cause problems. In addition to our efforts to improve the mechanism for preventing product jams, we have added a new way of preventing problems during purchase. We have implemented a structure where the product selection button of the vending machine will show that a product is sold out if a jam is detected in order not to inconvenience purchasers.

4. Features and Technology

4.1 DC gear motor system

We have developed a new structure that combines a cam-linkage mechanism with a DC gear motor. It serves as a low voltage DC drive source that operates at low voltage and can allow for quick round trip operation. Figure 4 shows how the driver source works in the new structure.

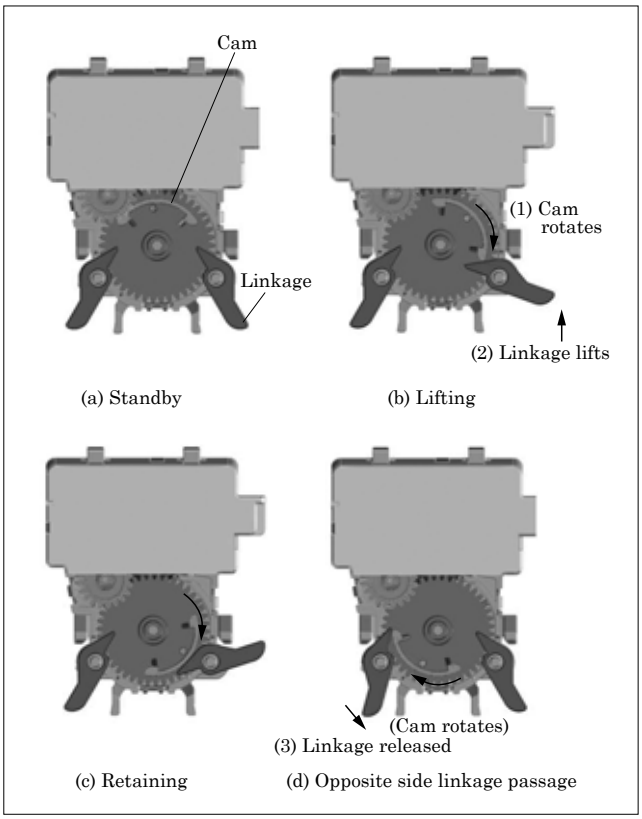

Fig.4 Drive source operation

In contrast with a conventional AC solenoid output of approximately 700 W, the DC motor has one-fifteenth the output of approximately 48 W due to constraints on space within the structure. First, we use a gear motor, which utilizes a gear to slow down a small, high-speed rotating motor, in order to ensure the required lifting power. The gear motor ensures a necessary reduction gear ratio in the limited space by using a worm gear while ensuring the required lifting power through obtaining an output torque approximately 25 times greater than the motor output. Next, we use a cam-linkage mechanism to ensure operation speed. We finely set the linkage contact surface angle to ensure a certain stroke amount, and ensure the required operation speed by obtaining the stroke required at the fine cam rotation angle.

In this mechanism, the vending mechanism flapper (see Fig. 3) operates to ensure that only the product at the bottom is sold and also other products stacked up are not accidentally sold. In order to perform this reliably, the mechanism is structured to increase the lifting speed of the linkage during the lifting operation shown in Fig. 4 (b). We also designed the structure so that the linkage is retained in the outer periphery of the cam, in order to ensure stable retention power without relying on drive power when held (see Fig. 4 (c)). With this structure, the retention status is maintained even if the power supply is shut down when held, allowing vending to continue once power is restored.

Although these structures ensure speed and retention power, the vending mechanism also needed to support a wide variety of vending product shapes, materials and sizes. With conventional AC solenoids, even if the lifting operation of the vending mechanism stopped without reaching sufficient speed for products with large diameters or square shapes, the product would be retained without causing any errors such as locking at the position it stopped. However, with a DC gear motor system, an additional mechanism was required to prevent the motor from locking.

We therefore used a plastic linkage to design a mechanism that uses part deformation caused by elasticity. Depending on the shape of the product, the mechanism may appear to come close to stopping during lifting operation. However, the linkage rotation shaft separates from the cam due to elasticity, allowing the cam to rotate. This allows the lifting operation to function properly where it would otherwise stop.

4.2 2 in 1 drive system

It is desirable for operators to use vending machines capable of carrying a wider selection of products that can be sold, as well as higher numbers of individual products. For this reason, the vending mechanism was conventionally installed so that it was interlinked. The drive sources were embedded in a limited and narrow space, with each drive source driving one column.

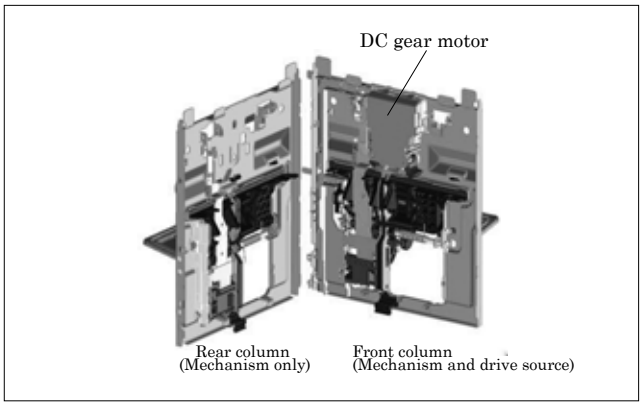

Fig.5 1 motor, 2 column drive system

If the DC gear motor was placed in the same location, it would not be able to secure the space required to gain a sufficient gear reduction ratio and cam radius. We leverage the interlinked structure to drive 2 columns with a single motor, ensuring the space that was needed (see Fig. 5).

The front and rear columns use the same gear motor and the sold-out detection drive source, as described later, making it possible to design a vending mechanism that collects all the electric driving parts on a single side, achieving improved maintainability.

4.3 Sold-out detection

Figure 6 shows the sold-out detection structure. In this structure, a detection switch detects whether vending products are applying a load to the pedal. The rear column sold-out detection switches are all brought to the front column in order to improve maintainability. Furthermore, since the detection switch detects a pedal movement it can detect the dispensing state in

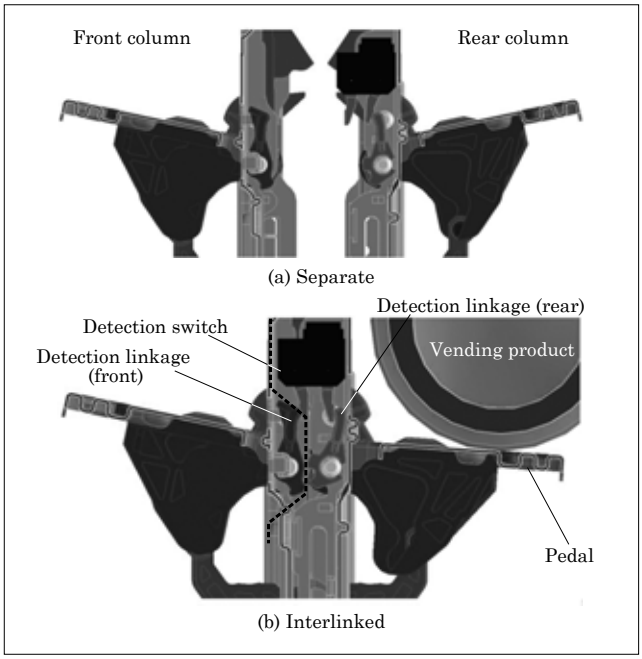

Fig.6 Sold-out detection structure

addition to whether a product is sold out. Detecting errors such as jammed products allows for more detailed support based on actual circumstances.

Conventional sold-out detection mechanisms set vending products as sold out when the last one of a product still left in the machine. This new mechanism can detect the last product remaining. This means that vending products can be sold to the last item. This increases the number of products that can be sold by an average of 7%, reducing lost sales opportunities. In addition, conventional detection mechanisms used shape detection method, and they sometimes were unable to detect products with large dented shapes. The new mechanism adopts weight detection method. Since there are no restrictions on shape, operators have much more freedom in choosing the shape of products they sell. Finally, the new mechanism directly detects vending products. This allows it to accurately determine that products are in the standby position and to prevent erroneous product detection.

4.4 Jammed product detection and payment refunds

Figure 7 shows a comparison of processing when a failure occurs. The DC gear motor system and the new sold-out detection mechanism detect when mechanical vending operations are complete, making it possible to detect column failures. Product jams can be identified when motor rotation stops and the origin switch of the gear motor does not detect that it has returned to its original position.

Conventional vending mechanisms were not able to detect product jamming. Consequently, there were troubles in some cases when a purchaser occasionally intended to purchase a product even though the product could not be dispensed or there was a column failure. We have developed status detection for this mechanism, which allows it to refund payment or have the purchaser select a different product if a product becomes jammed. Additionally, separating a defective column allows purchasers to prevent from selecting products that cannot be dispensed, drastically reducing problems during purchase.

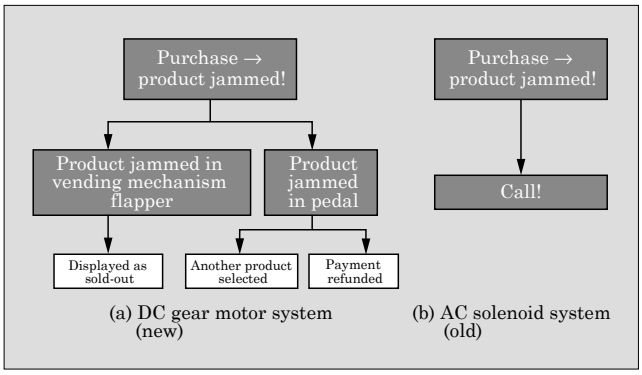

Fig.7 Comparison of failure handling processes

Table 1 Vending mechanism performance

Item	New mechanism	Conventional mechanisms	Comparison
Drive voltage	24 V DC	100 V AC	Low voltage drive
Error detection	Yes	No	Able to detect errors
Failure response	Refund/ selection of different product	Unable to detect	Prevents selection of unavailable products
Defective column separation	Able to separate →Vending stopped	Unable to separate	Prevents problems during purchase
Defective column confirmation	Display by remote control	Confirmation by actual vending	Serviceability improved
Operating noise (dB)	70	73	−3 dB
Sold-out detection	Zero	One product remaining	−7% Reduced sales opportunity losses
Product detection range (mm)	169	35	480% Improved freedom in choosing package shape
Power consumption (W・s per item)	17	175	−90%
Power consumption (W)	48	700	−93%

5. Results

Table 1 lists the performance gained as a result of developing this mechanism. As an added benefit, reducing power consumption also made it possible to reduce the volume and capacity of batteries used with disaster response models by 40% compared with conventional products.

6. Postscript

This paper described a product dispensing mechanism for vending machines in the global market. Developing this mechanism has allowed us to build technology to achieve low voltage DC drive sources. We will promote technology expansion based on this technology, in order to provide global support for drive sources in vending machines. We will continue our research and development efforts with a focus on providing added value to our customers.

IEC Standard Compliant Glass Front Vending Machine "Twistar"

SAKA, Mitsuhiro* MATUSMOTO, Masahiro* WATANABE, Tadao*

ABSTRACT

To meet the needs for China and ASEAN region, where needs of vending machines are increasing in retail business, Fuji Electric should acquire international certifications and deal with diversity of vending products. In light of this, we have developed the IEC standard compliant glass front vending machine "Twistar." This product utilizes an energy-saving panel housing structure suitable for overseas production and achieves simple control through the integration of the control board and software individually. Furthermore, mounting 4 types of vending module mechanisms can sell all products by one vending machine. We have also developed a soft-handling mechanism for the conveyance elevator to prevent the deformation of products.

1. Introduction

Beverage and food vending machines have currently reached a state of market saturation in Japan, with a total of approximately 2.63 million machines installed. Locations where new vending machines can be installed are limited and demand is focused mainly on replacing existing machines. The Japanese market is entering a period of maturity. The total number of installed beverage vending machines is expected to trend downward due to declining birth rates. As a result, beverage manufacturers, who are the main customers for vending machines, are attempting to reduce investment in vending machines in the form of initial costs, and are deploying energy saving vending machines as a means to reduce running costs in order to make profitability improvements.

Meanwhile, lifestyles are changing in China and Association of Southeast Asian Nations (ASEAN) regions due to economic growth. The light meal and soft drink market has grown by more than 10% over recent years in such countries, and there is a growing need for "vending machine sales" in the retail business. Although there are no official statistics on the total number of installed vending machines, it is estimated that there are approximately 70,000 to 80,000 in China, and roughly 100,000 in ASEAN regions. In terms of product life cycle, vending machines in such countries have entered the introductory period.

2. Development Background

Demand is expected to increase in China and ASEAN regions, focusing on places where people gather, such as factory cafeterias and rest areas, public facilities (airports, train stations and halls) and office buildings.

Fig.1 Glass front vending machine "Twistar"

In order to meet this demand, we have developed the IEC standard compliant glass front vending machine "Twistar" (see Fig. 1).

3. Development Goals and Challenges

There were 3 major issues in developing Twistar. The first issue was to launch production at a new factory in Thailand. The second issue was to obtain international certification in order to expand vending machine sales in ASEAN regions. The final issue was to support a wide variety of products so that vending machines could function as general-purpose machines and sell more types of beverages. Our specific objectives were as follows:

(1) To develop a housing structure suitable for overseas production

Use a panel housing structure that can save energy.

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(2) To achieve simple controls that conform to IEC standards

Obtain international certification for product safety testing by obtaining IEC product safety standards in the form of international certification (CB report).

(3) To increase general versatility

(a) To diversify types of product vending mechanisms

In addition to the 2 types of standard modules, develop new replaceable vending modules for small products and beverage products.

(b) To use soft-handling for product conveyance

Use a product conveyance (soft-handling) system that is gentle on products, to allow products subject to damage to be sold.

4. Features

4.1 Overall structure

Figure 2 shows the internal configuration of Twistar. The heat-insulating layer inside the unit is composed of the body heat-insulating layer surrounding the product storage rack area, and the insulated glass and door heat-insulating layer installed on the door component. Products are stored in the storage rack's spiral component (standard vending module). When a product is sold, the spiral component is rotated and the product is dispensed, whereupon the vertical conveyance elevator sends the product to the product delivery window toward the bottom.

4.2 Panel housing structure

Conventional housings were manufactured on semi-automatic integrated production lines that cover the manufacturing process from bending the sheet metal to welding and painting. This required production lines for welding, cleaning, painting and assembly transport. In response, we developed a new housing that would allow us to begin production quickly in our new Thailand factory. The housing was designed to be assembled on an assembly stand. In addition to combining the painted sheet metal with the heat insulating material into a single unit, the panel was designed so that each wall is an independent piece. In doing so, we have minimized facility installation time and costs (see Fig. 3).

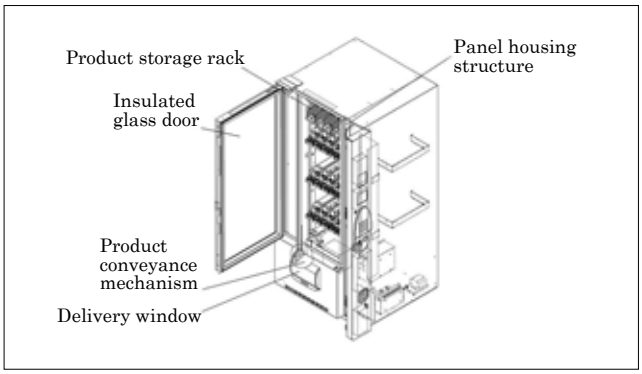


Fig.2 Internal configuration of "Twistar"

In developing the panel housing structure, we paid consideration to overseas production as well as energy saving. Conventional housings had issues on heat insulation at joints. In response, we heated the inside of the unit using an electric heater, and used a thermal camera to visualize heat distribution with a certain temperature difference kept between the inside and outside of the unit, then evaluated insulation performance (see Fig. 4).

Based on our evaluation, we then investigated how to enhance insulation performance in required locations. Airflow in conventional machines involves a discharge duct located toward the front on the side of the housing and a suction duct located on the rear of the housing. The structure was complicated and there were many components. Figure 5 shows our airflow design and the results of running a simulation. Additionally, the discharge duct and front glass are closely located in order to cool products toward the front glass. Consequently, the blowing temperature is low and the front glass is directly cooled. It was necessary to suppress the amount of heat entering from the front glass, 3 layers of glass were therefore used. Then, we adopted a panel housing structure that features the simplest structure possible. It does not require a suction duct and instead has a front suction and rear discharge. We needed to reduce air volume variation, which causes beverage product temperature fluctuation at each shelf. We ran simulations and de-

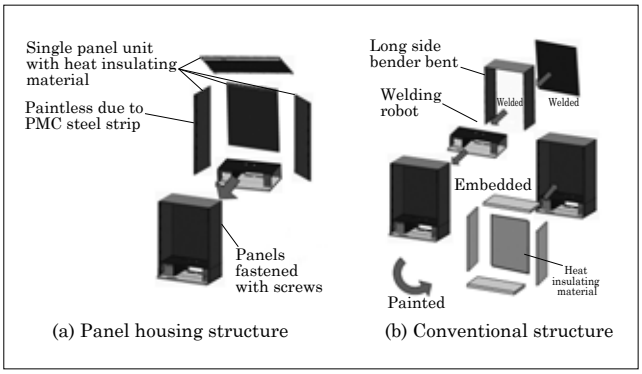


Fig.3 Housing structure

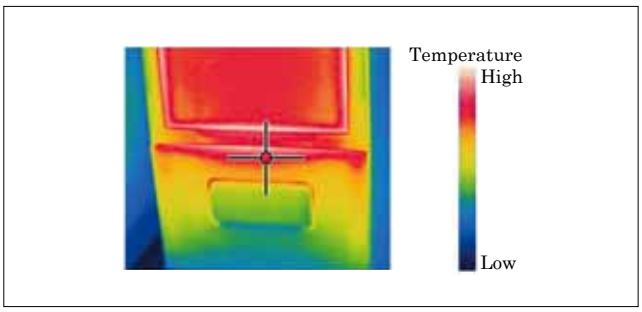


Fig.4 Example of heat distribution at lower front of vending machine

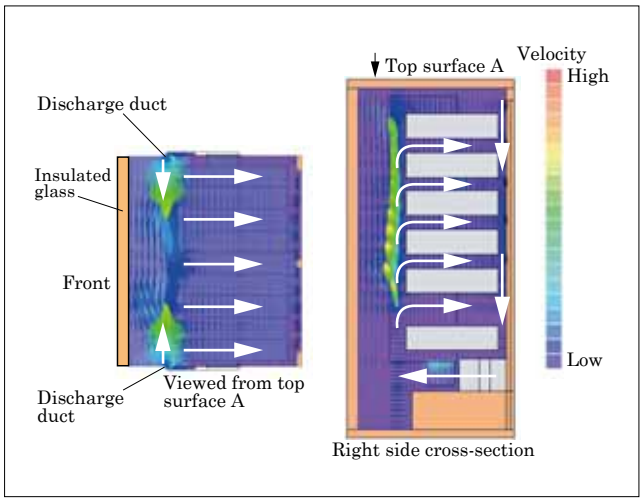


Fig.5 Airflow design and simulation results (conventional structure)

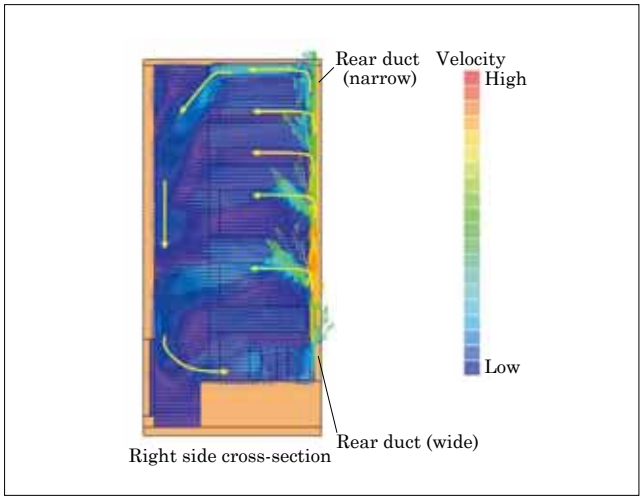


Fig.6 Airflow design and simulation results (panel housing structure)

cided on the ideal airflow design (see Fig. 6). To reduce the airflow concentrated at the top shelf, we changed the dimensions of the rear duct so that the upper portion is narrower than the lower portion. We made a range of improvements such as slowing down airflow around the front glass, reducing the amount of heat entering through the glass by 29% compared with conventional machines even if 2 layers of glass are used instead of 3. Finally, we reduced the temperature fluctuation of subsequent vending products in all columns in the product storage racks to 2.6 K, down from 3.5 K for conventional machines.

4.3 Simple controls

Control functionality for conventional vending machines was performed by a master board and slave board, in consideration of providing the machines with general versatility. However, the new design uses a specialized integrated control board that combines the master board and slave board in a single unit. In order to make the control boards a single unit, we narrowed functionality down to what is essential for vending machines: cooling and vending. The conventional control system contains the master board, dispensing slave board and remote control board, and each equipped with its own software. The new integrated software design uses a simple structure with fewer functions (see Fig. 7).

For money processing, we applied a multi-drop bus (MDB) system, which is generally used overseas, in addition to the conventional vivid transaction system (VTS). We designed the control system to check which system is connected when the vending machine starts up, then communicate using the system that is connected. Magnetic cards, contactless IC cards and POS systems are very region-specific, and compatibility varies from one country to another, creating the need for additional processing such as matching. To allow the vending machine to meet the specifications in each country, we created adapter boxes to share information on the interface. We also prepared equipment for software matching tests to make it possible to conduct tests locally in each region (see Fig. 8).

In order to obtain international certification (CB report) that proves compliance with IEC product safety standards, we developed this product after investigat-

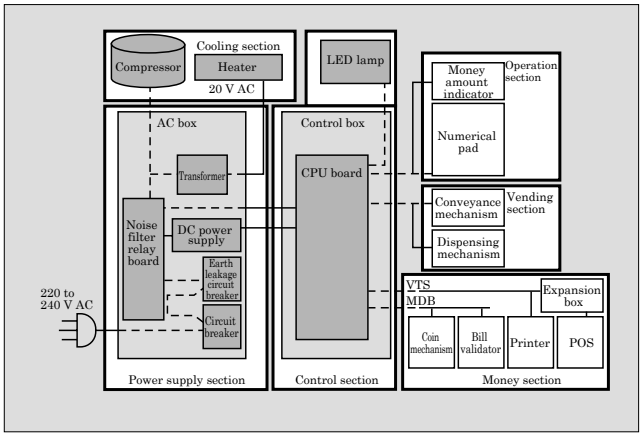


Fig.7 Control system configuration

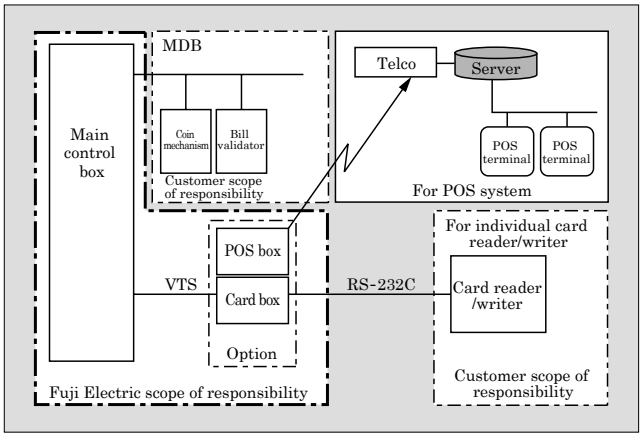


Fig.8 Money processing system configuration

ing differences with the “Electrical Appliances and Materials Safety Act” that vending machines in Japan normally comply with.

We found that we needed to support the radiation emission test (10 m method), which is not stipulated int he “Electrical Appliances and Materials Safety Act.” To support this, we made the following improvements to the DC power supply unit, reducing radiation emission (see Fig. 9).

(1) Turn-on time delay

We delayed the turn-on time for the primary side switching circuit. This reduced the high-frequency radiation emitted by pulse components on the differential side (see Fig. 10).

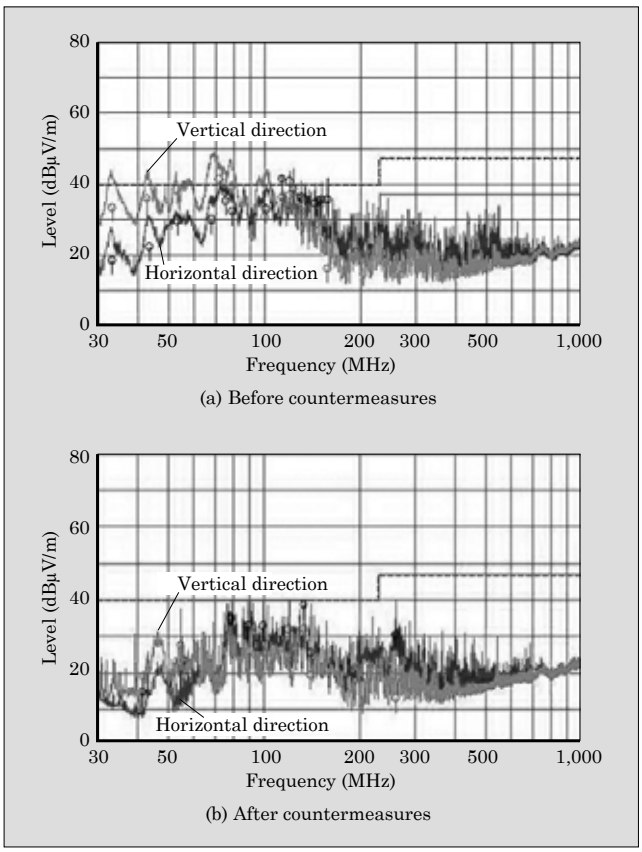


Fig.9 Radiation emission from vending machine

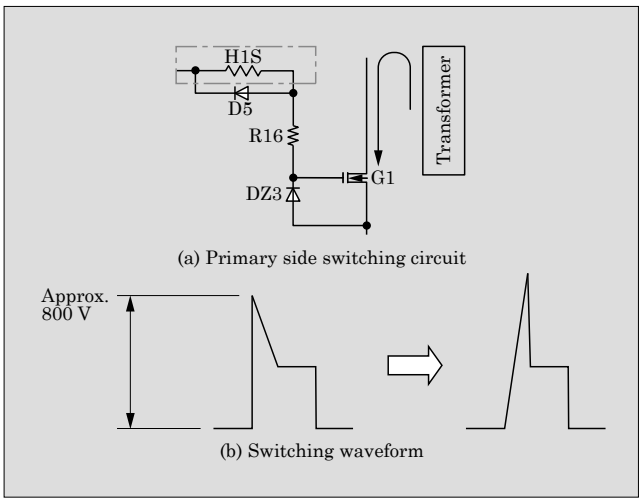


Fig.10 Turn-on time delay

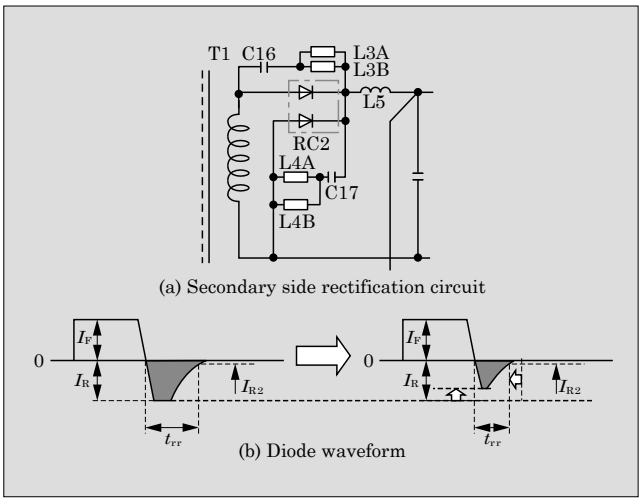


Fig.11 Modification of secondary side rectification circuit

(2) Modification of secondary side rectification circuit

Changing from a fast recovery diode (FRD) to a Schottky barrier diode (SBD) reduced radiation levels by 5 dB (see Fig. 11).

4.4 Increased general versatility

In developing this product, we were required to develop sales specifications, detailing information such as what kinds of products are sold in glass front vending machines in ASEAN regions. We then investigated to identify strong selling products in each country.

After mapping strong selling products in each country by size, we were able to categorize products into 42 sizes. Beverage products with diameters ranging from 43 to 75 mm showed the most sales demand. We learned that there were many products of varying sizes and shapes that are not available in the Japanese market, from snacks with a thickness of 7 mm, to large cup noodle products with diameters of 150 mm. We therefore made it possible to sell all products with

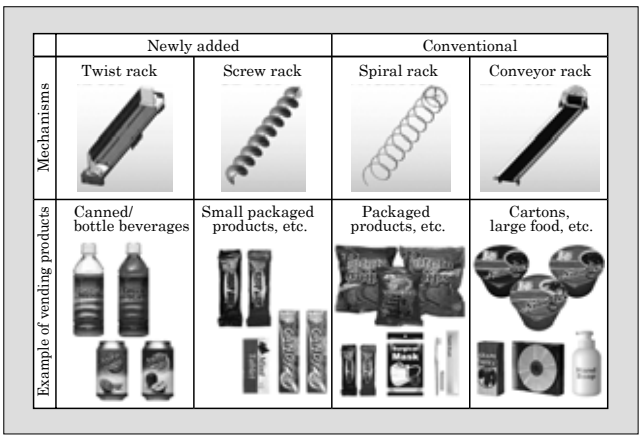


Fig.12 Vending module mechanisms and example of vending products

a single machine, merely by replacing the vending mechanism. In order to accomplish this, we developed 2 types of new vending module mechanisms that offer improved storage density and operability, in addition to the 2 types of conventional vending module mechanisms (see Fig. 12).

When products are passed to the delivery window in conventional machines, the product is passed using the momentum of the conveyance operation after the product is conveyed by the vertical conveyance elevator. During the process in which the product is placed and conveyed, the conveyance base must be lowered to the delivery window while gradually decelerating. In this case, we generally use a control system to pulse drive a stepping motor, which results in a complex control system. To address this problem, we used a DC motor in the vertical axis drive, used encoder pulse signals to control the height of the operation path, and controlled acceleration and deceleration of the motor using pulse width modulation (PWM). As a result, we were able to implement a soft-handling mechanism (see Fig. 13) for product conveyance to lower the conveyance base to the delivery window while decelerating it gradually. This soft-handling mechanism makes it possible to prevent product deformation and damage.

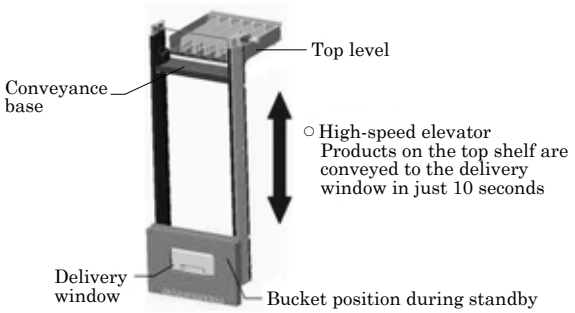


Fig.13 Soft-handling mechanism for product conveyance

5. Postscript

This paper described the IEC standard compliant glass front vending machine "Twistar." Developing this product from a global perspective allowed us to overcome language, culture and custom barriers standing in the way of accomplishing our goals. We will continue to deepen interaction between our mother factory in Mie and our overseas sites, gather detailed information on the needs of our customers and work towards developing strategic products.

Currency Identification Device for Global Markets "FGC Series" and "FGB Series"

OIWA, Takeshi* TANAKA, Nobuyuki* YAMANE, Takuya*

ABSTRACT

Fuji Electric has developed the "FGC Series" and "FGB Series" currency identification devices for global markets such as China and Association of Southeast Asian Nations (ASEAN) region. To speed up the commercialization of the devices according to the various kinds of size and design of currencies by modifying a portion of the components and software, we have implemented a common design, in which base components and configuration are standardized. Furthermore, we have met an identification performance to ensure reliability by equipping a coin handling device (coin mechanism) with a coin escrow function and new inspection algorithm that enhances the identification of material, as well as equipping a paper currency identification device (bill validator) with a line sensor and identification algorithm.

1. Introduction

Fuji Electric has manufactured coin handling devices (coin mechanisms) and paper currency identification devices (bill validators) as currency identification devices to be installed in vending machines. This paper describes the "FGC Series" coin mechanism for global markets and the "FGB Series" bill validator for global markets that have been developed in consideration of China and the Association of Southeast Asian Nations (ASEAN) region. This paper also presents their respective features and elemental technologies.

2. Background of Development

The Japanese vending machine market has been gradually shrinking recently in terms of both the volume of shipments and sales per unit. Accordingly, the volume of shipments of coin mechanisms and bill validators, which are installed in vending machines, is on the decrease in the same way. Fuji Electric is actively advancing into other automatic equipment markets such as those for payment machines for coin-operated parking lots and ID photo booths. However, this is not sufficient to cover the decline in the vending machine market.

Due to such domestic market conditions, it was necessary for us to depart from the existing products and markets. As a result of analyzing the past expansion of the vending machine market in Japan, we have identified many factors such as the sales strategies and equipment service systems of beverage manufacturers. From the perspective of equipment (coin mechanisms and bill validators), one factor is that they have been able to quickly handle new coins and bills. We have considered advancing into new overseas markets by utilizing this strength.

In Japan, vending machines rapidly became popular along with the country's high economic growth. China is currently in a situation similar to that period in Japan and Fuji Electric has been marketing coin mechanisms and bill validators there since 2004. With vending machines becoming increasingly familiar among Chinese people and the sales and service systems of manufacturers gradually put in place in the last few years, diffusion of vending machines is expected to accelerate. In addition, Southeast Asian countries such as Thailand and Malaysia, although unpredictable, have the potential to see an expansion of the vending machine market in the same way as China, with a lag of a few years. Figure 1 shows Fuji Electric's sales forecast for the coming 3 years in the Chinese market.

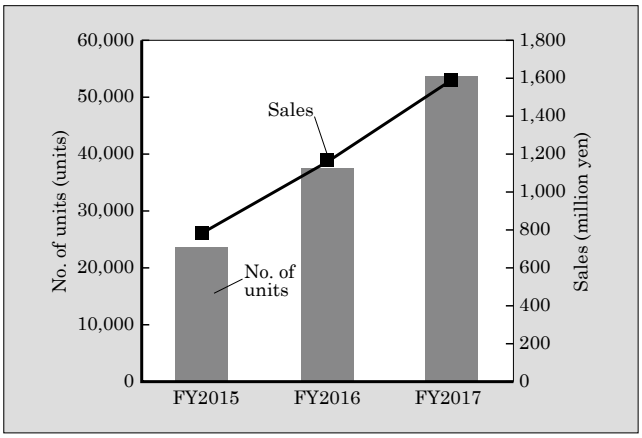


Fig.1 Sales size forecast of Fuji Electric's vending machines in Chinese market

* Food & Beverage Distribution Business Group, Fuji Electric Co., Ltd.

3. Aims of Development and Challenges

For a global launch, we have aimed to standardize as many components as possible and realize a performance equivalent to that of the optimum design for the respective countries. We have made the products compatible with different coins and bills of different countries simply by preparing multiple types of change storage for the coin mechanism and of passage parts of the identifying unit for the bill validator.

4. "FGC Series" Coin Mechanism for Global Markets

A coin mechanism is equipped with functions to identify deposited coins, sort and store them into dedicated tubes and pay out change.

Figure 2 shows the external appearance and configuration of the FGC Series that has been developed. Basically, the mechanism is composed of 4 units and is designed to achieve standardization. It is only necessary to replace some of the components or add an attachment to make it compatible with different countries' currencies. This has made it possible to support currencies of countries that come in small physical quantities.

4.1 Features

We are the first to provide a coin escrow function (see Section 4.3), which temporarily holds the deposited coins, for the FGC Series. Regarding the control method, we have provided interfaces to support both the multi-drop bus (MDB) protocol, which is the mainstream outside Japan, and Japan Vending Machine Manufacturers Association (JVMA) scheme, a Japanese standard.

Table 1 shows the major specifications of the FGC Series.

Table 1 Major specifications of "FGC Series"

Item		Specification
Applicable coins		Coins of various countries
Coins paid out as change		Coins of various countries
Change storage tube	No. of tubes	5
	Change storing method	Cassette tube method (with attachment/detachment detection)
	Cassette opening/closing function	Provided (with 2-piece cover)
	Tube switching function	Provided (E tube: denomination changeable)
	Locking mechanism	Provided (padlock installable)
Change payout	Payout structure	1 DC motor + 5 clutch SOLs switched in-between
	No. of coins paid out simultaneously	2 max.
	Recovery control	Provided
Coin escrow function		Provided
Drainage structure		Provided (drainage chute installable)
Control method	MDB	Available
	JVMA	Available
	Bill validator connection function	Provided (MDB bill validator)
Power supply	MDB connection	24 V DC ± 10%
	JVMA connection	24 V DC ± 10%
Rated current consumption	Standby mode	0.3 A or less
	Operating mode	1.0 A or less
	Peak	1.5 A or less
Operating temperature range		−15 °C to +60 °C
Dimensions		W138.0×H356.2×D82.3 (mm)
Mass		Approx. 2.0 kg

4.2 New coin validation sensor

The coin validation sensor for judging the authenticity of coins traditionally had a coil sensor that was directly bonded on the housing. With the FGC Series, a bobbin-shaped sensor is soldered on a printed circuit board, which is screwed to the housing. Since it does not use any adhesive, the number of quality control items decreases, leading to improved quality. Figure 3 shows the configuration of the coin validation sensor.

In addition, the new coin validation algorithm with

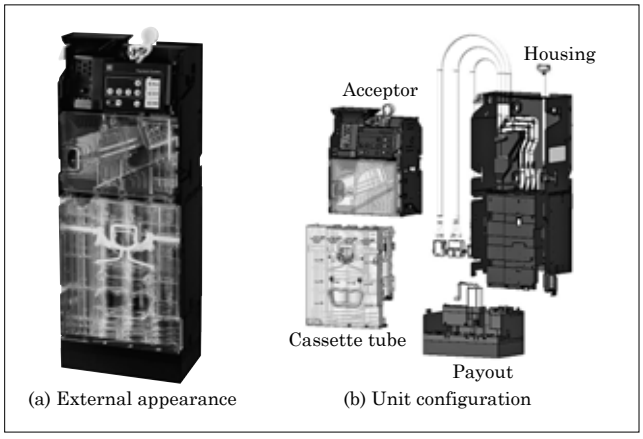


Fig.2 External appearance and configuration of "FGC Series"

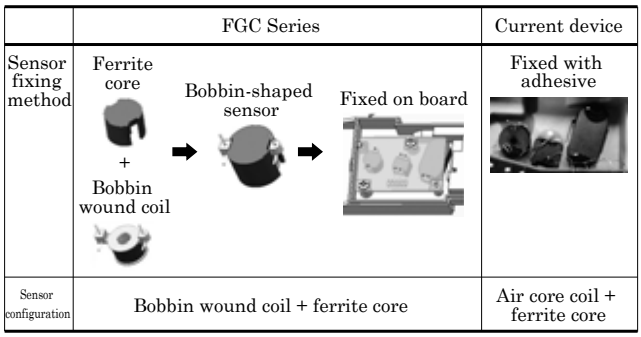


Fig.3 Coin validation sensor configuration

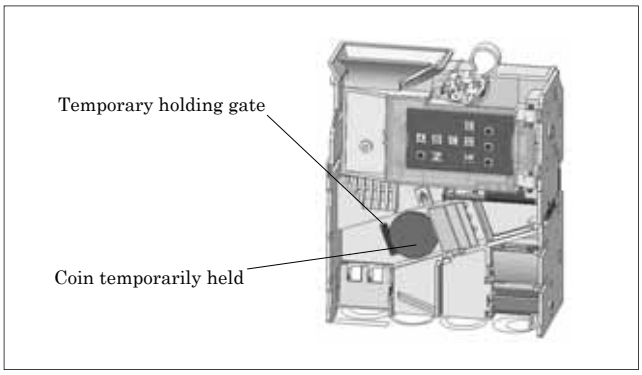


Fig.4 Acceptor unit (with front cover removed)

an enhanced ability to identify ferrous materials offers support for a wider variety of sizes and materials of coins than in the past.

4.3 Coin escrow function

The acceptor unit has a coin escrow function. As shown in Fig. 4, the temporary holding gate holds the coins and, when the return lever of the vending machine is pressed, the coins held are returned as they are. This prevents counterfeit coins from being used. In Japan, this function was devised by Fuji Electric ahead of other companies in the industry. We have developed this technology for the FGC Series to improve the reliability of vending machines, which sell items without any human operator.

4.4 Opening and closing cassette with changeable tube diameter

Coins used in different countries greatly vary in terms of their outer diameter, thickness, material, and other properties. Therefore, we have designed the basic dimensions of the cassette according to the maximum diameter and thickness of such coins. We have made the product capable of dealing with diameters or thickness smaller than the basic dimensions simply by replacing components or adding an attachment.

As shown in Fig. 5, the structure makes it possible to open and close the front and side of the cassette for easy coin replenishment, which is one major feature.

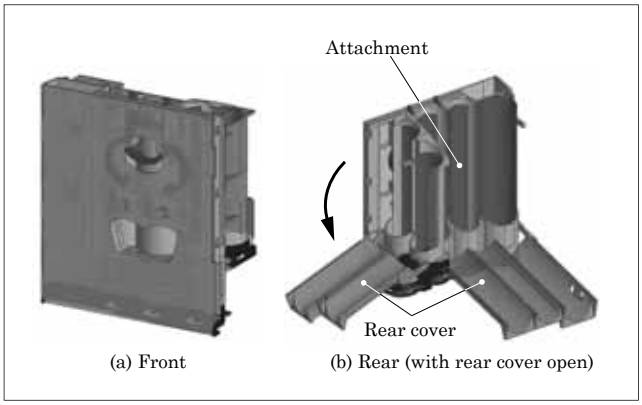


Fig.5 Cassette tube

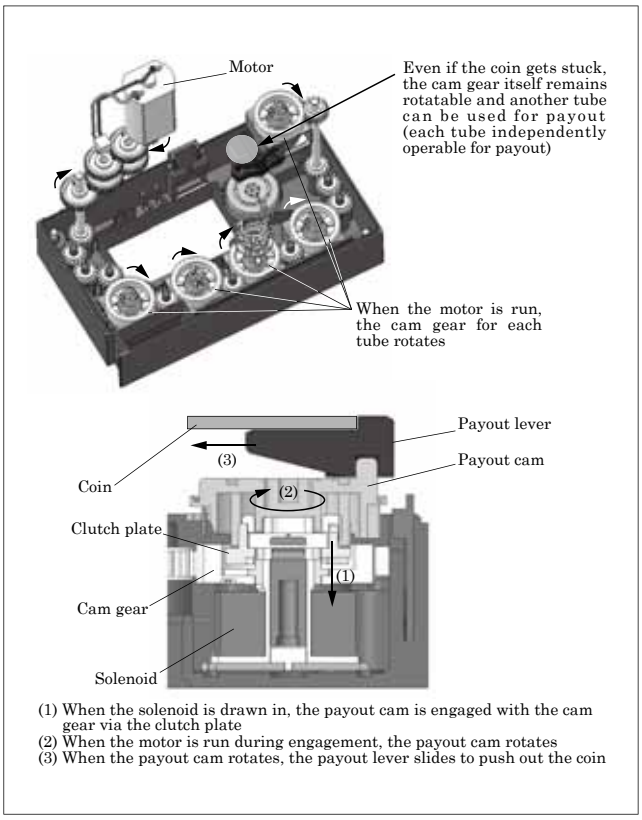


Fig.6 Independent payout mechanism

4.5 Independent payout mechanism

As shown in Fig. 6, a solenoid provided at the bottom of each tube is used to move the clutch plate up and down. This engages and disengages the cam gear and payout cam (green). When the motor is run, the engaged cam gear and payout cam rotate. When the payout cam rotates, the crank mechanism causes the payout lever to slide, which pushes a coin in the change tube for payout.

In this structure, if a coin of the denomination to be paid out gets stuck for any reason, the gear for the tube for that denomination is disengaged by turning off the solenoid. The cam gear itself remains rotatable and turning on the solenoid for another payout tube to engage it allows money to be paid out from an alternative tube.

5. "FGB Series" Bill Validator for Global Markets

A bill validator is a device that identifies, conveys and stores deposited bills. Figure 7 shows the external appearance and configuration of the FGB Series.

To make a bill validator compatible with bills of different countries, technology is necessary that allows the device to identify a variety of bills such as those made of polymers or other non-paper materials. It is also necessary to identify currencies of many different designs and color shades. In addition, technology is required for conveying and storing bills of various sizes.

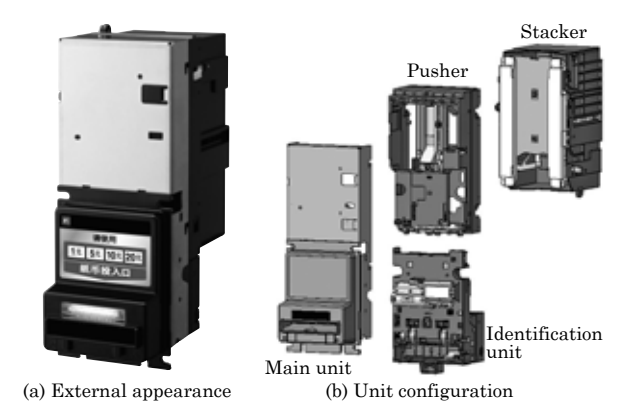


Fig.7 External appearance and configuration of “FGB Series”

5.1 Features

For the FGB Series, we have worked on developing products with the focus on the following points in order to deal with a variety of bills of different countries.

(1) Standardized design for series

The basic components and configuration have been standardized to make the product capable of accepting bills of different countries. This can be done simply by changing some of the components, the type of sensor and identification software.

The widths of the bills that can be accepted are 62 to 77 mm. If the width of the passage is specified to be 78 mm to handle 77 mm bills, those with a width of 62 mm may be significantly displaced laterally in relation to the direction of conveyance. Lateral displacement causes the position of the bill that passes over the identification sensor (trace line) to move, making it impossible to read the features of the bill. Providing a mechanism that centers bills is effective but makes the structure complicated.

Accordingly, with the FGB Series, the device has been developed to handle 3 different widths (66 mm, 70 mm and 72 mm) in addition to 78 mm to structurally minimize the lateral displacement. In addition, a line sensor has been used as the identification sensor so that lateral displacement can be corrected with identification software.

(2) Ease of maintenance

There are not as many service bases overseas as in Japan and vending machine installers called operators engage in product replenishment and maintenance. To be able to restore items without difficult maintenance work in the event of failure, a structure that allows operators to easily clean and replace maintenance parts is required. Accordingly, we have designed a structure with the focus on making it easier to replace maintenance parts, as described in Section 5.2.

(3) High reliability

We have realized a structure that accepts banknotes of different countries while ensuring the device’s identification performance, which is a fundamental requirement, and reducing bill jams. For the identification performance, we have made use of the simulation technology that evolved with bill validators for the Japanese market to construct an identification algorithm and taken advantage of the sensor correction function. To prevent bill jams, a scheme to reduce the conveyance resistance in bended bills by employing a large roller has been incorporated into the basic design.

Table 2 shows the major specifications of the FGB Series.

Table 2 Major specifications of “FGB Series”

Item		Specification
Applicable bills		Banknotes of various countries
No. of bill insertion slots		1
Insertion orientation		4 longitudinal orientations
Bill conveying system		Automatic pull-in and return by DC motor
Identification time		Approx. 1.4 s
Cash escrow function		Provided (1 bill)
Pull-out prevention function		Provided
Control method	MDB	Available
Power supply	MDB connection	24 V DC ± 10%
Rated current consumption	Standby mode	0.2 A or less
	Operating mode	2.5 A or less
Bill storage		Stack cassette system (removable)
	Locking mechanism	Provided (padlock installable)
Storage full detection		Provided
Bill storage capacity		New notes sealed by government: 600 ± 85 notes Notes in circulation: approx. 400 notes
Operating temperature range		−15 °C to +60 °C
Mounting orientation		Inverted
Dimensions		W94×H246×D127 (mm) *Projections not included
Mass		Approx. 1.2 kg

5.2 Unit structure of maintenance parts

As shown in Fig. 8, maintenance parts that are not easy to disassemble (such as motors, gears, and conveying rollers) with the current model have been built into a unit for improved replaceability.

Maintenance units are secured with hooks rather than screws and can be removed without tools such as screwdrivers. In addition, any motor speed decrease or roller slip is detected, and an alarm is then indicated on the 7-segment LED on the back. This points to the unit that needs to be replaced before a failure occurs.

In this way, operators can provide high-quality maintenance without requiring special training even

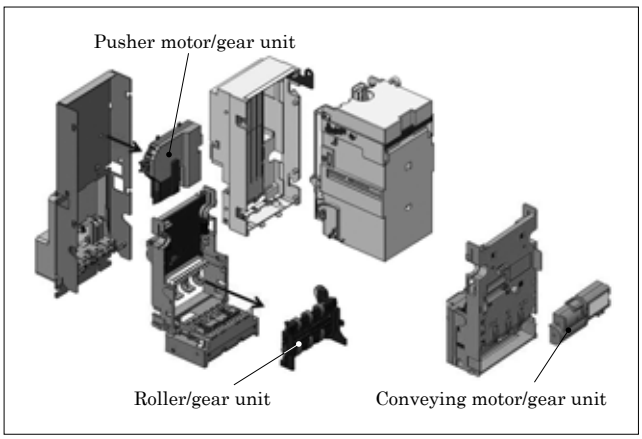


Fig.8 Unit structure of maintenance parts

in overseas bases where it is difficult to secure human resources with advanced skills.

5.3 Adoption of line sensor

With conventional bill validators, in order to meet the market demands for low prices and identification performance, the entire surface of a bill is not traced. Instead, the minimum number of sensors are used and they are composed of light emitting elements with the optimum wavelength and light receiving elements arranged optimally and discretely (discrete sensor method). With the FGB Series, a sensor structure is required that is capable of exhaustively accepting bills of many different countries. An image sensor that scans the entire surface of bills can deal with money from different countries, but is expensive. Accordingly, we have adopted a line sensor to provide a structure that can easily read features of bills of different countries and select the optimum wavelength. Specifically, a pattern that allows up to 12 sensors to be installed is provided. 3- or 2-wavelength sensors can be installed. Figure 9 shows an example of the line sensor's configuration.

5.4 Prism-based bill detection sensor

The concept was not to mount a printed circuit board near the slot to prevent it from water intrusion or damage. Hence, to detect a bill at the insertion slot, we have adopted a system of using prisms to guide the light to the sensor on the printed circuit board in the identification unit for detecting the bill (see Fig. 10).

With this system, the intensity of light decreases before it reaches the light receiving side. Factors in this light intensity decrease include ultraviolet degradation of the material, light intensity degradation due to dust, degradation caused by flaws on the bill conveying surface and degradation due to aging sensors.

With these factors of light intensity decrease taken into account, we have attempted to identify and set a target for the percentage of light guided by the prisms. This target needs to be ensured to allow bills to be detected with a combination of lower limit products of

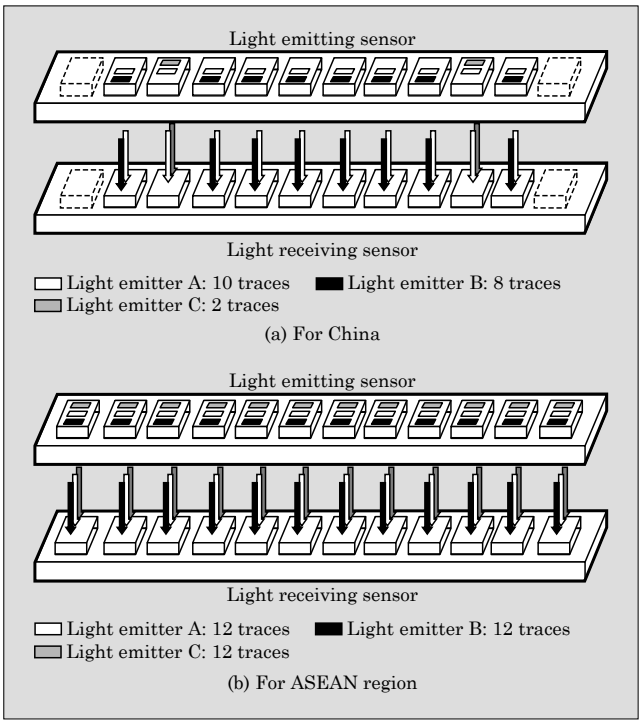


Fig.9 Line sensor configuration

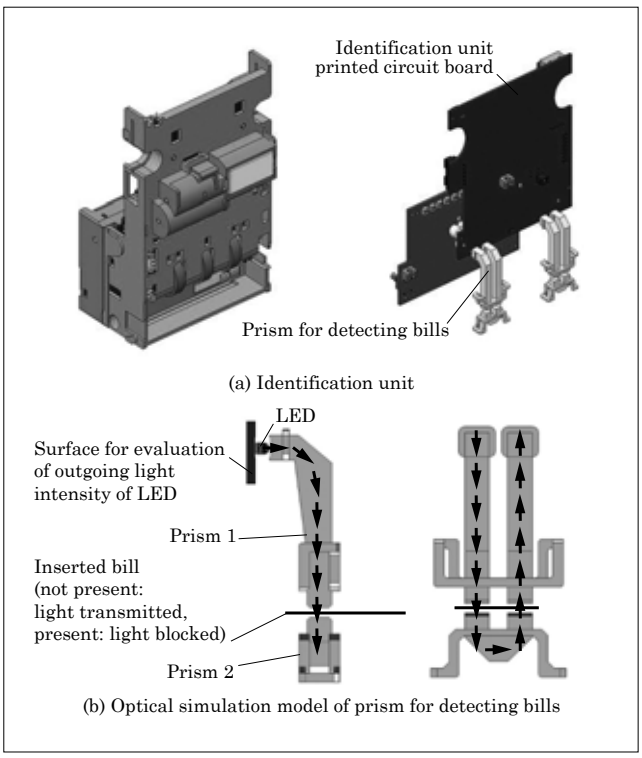


Fig.10 Prism-based bill detection system

light emitting and receiving elements. In this way, we worked on optimizing the shape of the prisms.

In addition, we have modeled related parts and made use of optical simulations to evaluate the outgoing light intensity of the LED. At the same time, we varied parameters such as the material, distance, cross-sectional area, angle of reflection and lens shape,

and made the optimum shape for efficiently guiding and condensing light to ensure the target intensity of guided light.

In this way, we have successfully reduced the number of parts while improving the reliability by not mounting the printed circuit board near the insertion slot and maintained the detection performance.

6. Postscript

This paper has described currency identification devices for global markets "FGC Series" and "FGB Series." In global markets, different specifications including security and ease of handling are required for different countries.

We intend to pursue convenience by further enhancing the products while observing the market trends to contribute to society.

Cooling Technology for Global Vending Machine Installed in High-Temperature High-Humidity Environments

MURASE, Takao*

ABSTRACT

We have been working on the development of a global vending machine capable of operating in environments with an ambient temperature of 40 °C and relative humidity of 75% in consideration of the maximum temperatures and humidities of the major cities in China. In addition to achieving our goal of supporting increased ambient temperatures, we have also developed an efficient operating control technology, as well as a heat insulating and cooling technology for efficiently cooling increased heat loads. With regard to the impact of frost that forms on evaporators in high-temperature and high-humidity environments, we have focused on evaporation temperature setting levels based on the result of observing the frost formation process, and by readjusting the setting levels we have been able to control the amount of frost formation. These measures have enabled us to achieve a reduction in the required cooling capability and a shorter initial cooling time even in high-temperature high-humidity environments.

1. Introduction

According to a survey conducted by the Japan Vending Machine Manufacturers Association, there were 2,568,600 beverage vending machines installed at locations throughout Japan as of the end of 2014, which is a 0.9% decrease from the previous year. Major reasons for the decrease of installations include a reduction in sales due to price increases following the increase in consumption tax, as well as a reduction in sales of canned coffee resulting from the increase in popularity of coffee beverages sold at convenience stores. On the other hand, subway stations, office buildings and factories in major Chinese cities have seen an increase of about 70,000 to 80,000 installations, and it is expected that this number will continue to rise in the future.

Fuji Electric has developed a global vending machine for installation in high-temperature high-humidity environments to support the development of growing overseas markets such as China. This paper describes the unit's cooling technology.

2. Development Background

In major Chinese cities, such as Shanghai, Hangzhou and Guangzhou, maximum temperatures get as high as 40 °C annually, making these high-temperature environments even hotter than that of Japan. Japan has its high-temperature environmental condition set at 32 °C and, as a result, has conventionally never had the need to verify operations in high-temperature high-humidity environments exceeding 40 °C. The low-temperature environmental condition (temperature of 5 °C) is the same as Japan, and thus verification has already been completed for this operation specification.

Development of vending machines for expansion into global markets such as China requires specifications that take into consideration high-temperature high-humidity environments.

3. Development Goals and Challenges

3.1 Challenges related to high-temperature high-humidity environments

The cooling capacity of vending machines is evaluated by the amount of thermal energy absorbed from inside the storage unit per unit of time. The amount of thermal energy is determined by the difference between an ambient or product temperature and a target temperature. A larger difference in temperatures indicates a larger amount of absorbed thermal energy, and as a result, requiring a high cooling capacity.

Furthermore, since thermal energy is proportionally distributed based on the time it takes until product cooling is completed, shorter target times for completion will result in higher cooling capacity required per unit of time.

Figure 1 shows the relationship between the time it takes for cooling to complete and the required amount of cooling capacity. In Japan, a period of 24 hours at an ambient temperature of 32 °C has been established as the standard for completion of cooling when cooling from the initial state, in which ambient and product temperatures are equal. A change in ambient temperature from 32 °C to 40 °C to accommodate the Chinese market will require an increase in cooling capacity of 1.4 times as a result of the increase in thermal energy due to the temperature difference.

Moreover, in consideration of the cooling that is

* Food and Beverage Distribution Business Group, Fuji Electric Co., Ltd.

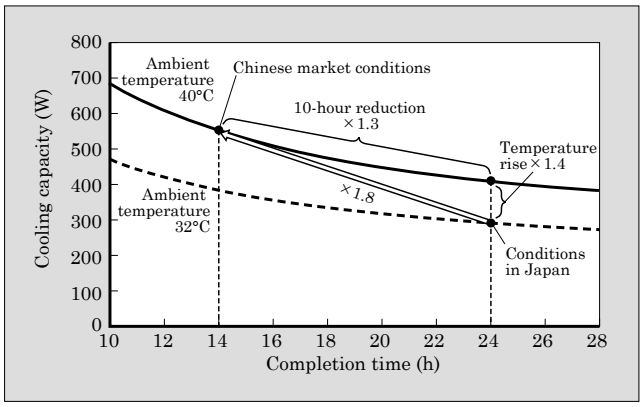


Fig.1 Relationship between completion time and required cooling capacity

required to restore the system to its stable state of operation after replenishing the unit with new product (restoration of cooling after replenishing), it is demanded that this restoration time be as short as possible to prevent loss of sales owing to the unit being in vending standby mode while it cools the replenished product. The Chinese market is requiring that the time necessary for the restoration of cooling after replenishing all of the unit's product be within 14 hours, which is 10 hours shorter than the 24 hours required by the Japanese market. In order to shorten the time for completing cooling by 10 hours, a cooling capacity of 1.3 times is required to implement initial cooling under the same ambient temperature conditions.

As a result, a restoration of cooling after replenishing that takes 14 hours at an ambient temperature of 40 °C requires a cooling capacity 1.8 times greater than the standard used in the Japanese market. Operation under the high ambient temperature results in decreased efficiency for the refrigeration unit, and this, in turn, causes a decline in cooling capacity. In order to secure high-efficiency cooling, measures need to be properly implemented with respect to heat loads.

Furthermore, even when relative humidity is the same, there is a greater amount of water vapor in the air when the ambient temperature is higher. As the temperature inside the storage unit decreases, water vapor condenses and this generates dew and frost. This dew and frost attaches to the surface of the fins of the evaporator (heat exchanger for cooling), and this reduces cooling efficiency. As a result, there needs to be some measures for preventing the adverse impact of this phenomenon.

3.2 Goals

In proceeding to develop a global vending machine, we had to establish design values for high-temperature and high-humidity ratings capable of meeting the environmental conditions of an ambient temperature of 40 °C and a relative humidity of 75%, which is an increase over the Japanese standard of an ambient temperature of 32 °C and relative humidity of 65%, while at the same time aiming to complete the restoration of cooling after replenishing within 14 hours, and working to improve cooling performance during initial cooling and restoration cooling. To accomplish this, we set forth the following 3 tasks:

(a) Establishing heat load assumptions, and securing insulation and cooling performance
(b) Reduction in initial cooling time based on optimized operation control
(c) Measures against frost

4. Characteristics of High-Temperature High-Humidity Environment Technology

4.1 Establishing heat load assumptions, and securing insulation and cooling performance

The required cooling capacity for the vending machine is determined by Formula 1.

Required cooling capacity =
outside invading heat + product heat load*1 ...(1)

To increase the required cooling capacity, a larger compressor or heat exchanger could be used, but since this will increase power consumption, it is not a desirable option. On the other hand, if the cooling heat load of the "outside invading heat" and "product heat load" is properly controlled, the required cooling capacity can be reduced, and this will make it possible to achieve a more efficient cooling system. We will now introduce 2 specific measures.

(1) Measures against outside invading heat

Figure 2 shows measures against outside invading heat. Heat that invades the storage unit from the outside increases in proportion with the difference in temperature inside and outside the storage unit. If an invading heat of 32 °C is taken as a base equal to 100, raising the ambient temperature from 32 °C to 40 °C will likewise increase invading heat by 28%.

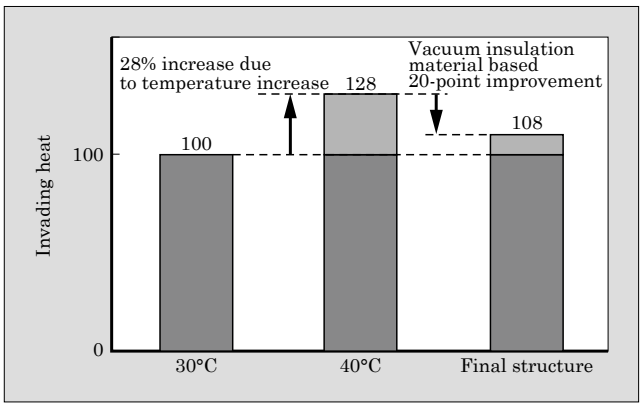


Fig.2 Measures against outside invading heat

*1: Product heat load: This refers to the sum total of thermal energy that needs to be absorbed when cooling products inserted in the storage unit in order to reach the appropriate temperature for dispensing.

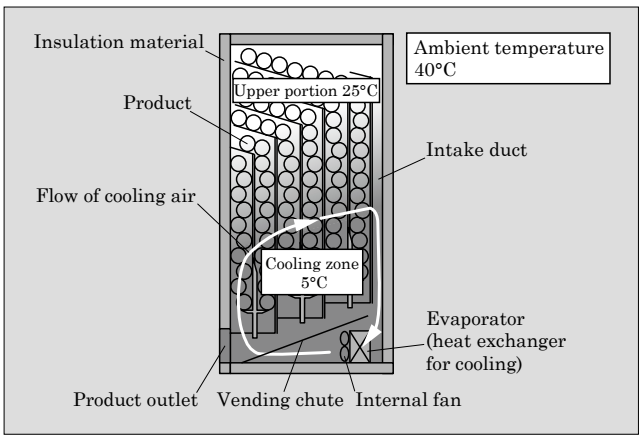


Fig.3 Overview of zone cooling

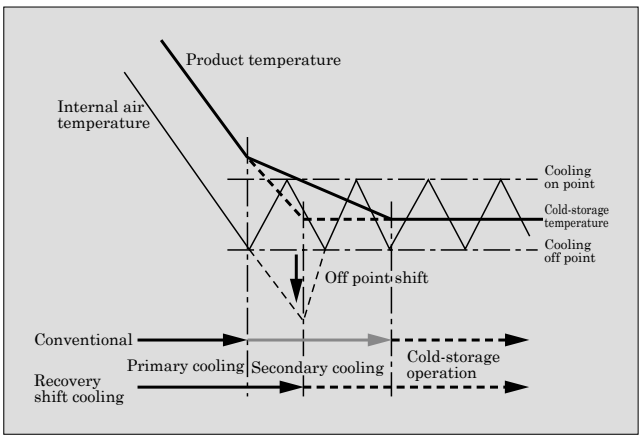


Fig.4 Overview of recovery shift cooling

Our current development makes use of vacuum insulation material for the heat insulation structure, resulting in a 20 point improvement in the heat insulation effect under a 40 °C environment. As a result, the increase in invading heat due to changes in ambient temperature is suppressed between 8% and 28%, and this, in turn, has suppressed the required cooling capacity.

(2) Zone cooling based product heat load measures

Figure 3 provides an overview of zone cooling. The required cooling capacity can be reduced by only cooling the portion of beverages subsequently available for purchase instead of the entire storage unit.

Our analysis of sales patterns in the Chinese market showed that it is possible to maintain proper cooling for beverages by cooling up to the 4th beverage in queue.

Our current development circulates cooling air in a limited zone that includes up to the 4th beverage in queue from the bottom. Zone cooling minimizes the product heat load to limit the number of products applicable for cooling, and this effectually reduces the required cooling capacity needed in the cooling system.

4.2. Reduction in initial cooling time based on optimized operation control

(1) Recovery shift cooling

Figure 4 provides an overview of recovery shift cooling. On-off control for the cold-storage operation has conventionally implemented cooling control based on the air temperature inside the storage unit as the cold-storage temperature level, and not based on the actual product temperature. This type of implementation initially cools the air temperature inside of the storage unit as opposed to the product temperature, and as a result, on-off control takes place before products reach their cold-storage temperature. Since secondary cooling is initiated during intermittent operations, the rate of product cooling is delayed, and the time it takes for products to reach their cold-storage temperature is prolonged.

Recovery shift cooling aims to reduce the time required in lowering product temperature to the cold-storage temperature by adding a control function for shifting down the on-off control temperature level during primary cooling when cooling begins. This type of control deliberately delays the detection of the off control when lowering the air temperature, enabling primary cooling to continue, and thus shortening the amount of time required in reaching the product cold-storage temperature. Recovery shift cooling reduces the time for reaching the cold-storage temperature to 2 hours and 20 minutes, which is an improvement over the conventional time of 3 hours.

(2) Shortening the defrosting period

Figure 5 shows a psychrometric chart. Assumed environmental conditions include a high-temperature high-humidity environment with an ambient temperature of 40 °C and relative humidity of 75%. The difference of the amount of water vapor between this environment and a stabilized cooling environment of 3 °C/95% is nearly twice that of the conventional standard of 32 °C/65%. A sufficient drop in internal temperature results in the water vapor inside the storage unit becoming frost that adheres and grows on the evaporator, instead of being discharged as drain water.

This phenomenon of frost formation obstructs the air-flow passage and decreases the heat-exchange

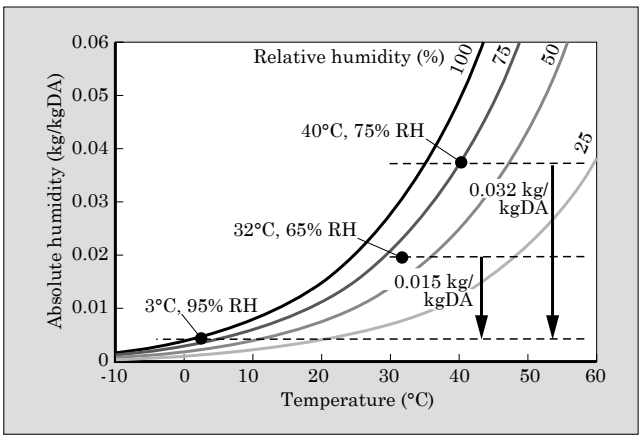


Fig.5 Psychrometric chart

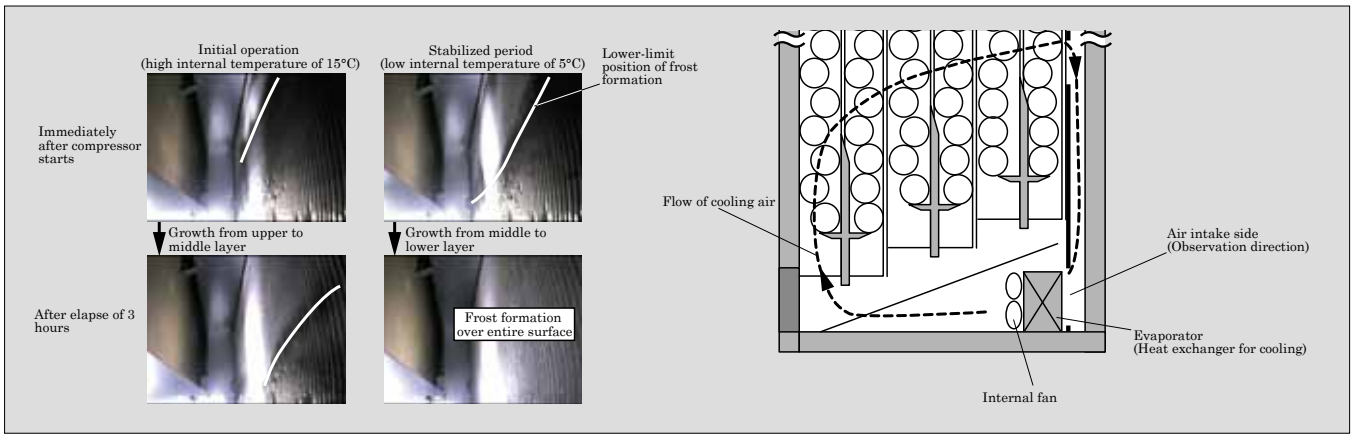


Fig.6 State of growth in frost formation on evaporator

efficiency of the evaporator, resulting in a state in which a sufficient cooling capacity cannot be attained. Furthermore, if freezing continues due to blockage created from frost located between the fins, the evaporator will stop functioning and this will prevent cooling inside the storage unit. Moreover, the amount of time required to stop cooling to implement defrosting by melting the frost is extended in proportion with the growth of the frost, and since the compressor will be stopped during this period, cooling will not be implemented inside the storage unit.

In order to suppress the amount of frost formation, the interval between defrosting operations had to be adjusted to shorter cycles, which means that defrosting will take place more frequently. By doing this, it has become possible to suppress growth in frost formation and prevent evaporator blockages due to frost, thus enabling stable cooling operations for the unit.

4.3 Measures against frost

(1) Verifying the growth in frost formation

We found that severe growth of frost formation occurs not on the exhaust side of the evaporator, but on the air intake side. Thus, we decided to install a compact camera for observing the state of the air intake side at all stages of operation including initial operation and stabilized operation. Figure 6 shows the state of growth in frost formation for the air intake side of an evaporator.

We learned that frost consistently forms on the upper portion (near the refrigerant inlet) even when the temperature inside the storage unit during initial operation is relatively warm (15 °C or higher). This is because frost begins to form when the surface temperature of the evaporator drops below freezing.

With regard to the evaporator, the lowest temperature occurs in the upper portion near the refrigerant inlet, and in contrast to this, temperature increases while moving toward the lower portion outlet. When both the temperature inside the storage unit and the temperature of the intake air are high, heat exchange is implemented and a state of high overheat*2 will occur, resulting in frost formation being limited to only the upper portion.

We were able to verify that lowering the temperature inside the storage unit to reduce overheat will cause the surface temperature of the evaporator to become gradually uniform with respect to the upper portion, and this temperature change is directly related to the expansion in the range of growth of frost formation. When frost is pervasive over the entire air intake surface, air flow will decrease. This also further accelerates the forming of frost, leading to blockage.

Once a state of blockage occurs, air circulation will be lost and heat exchange will not be implemented until defrosting takes place. During defrosting when the frost is being melted, the temperature of the evaporator will be maintained at 0 °C. The duration of the melting is proportional to the amount of frost formation, and recovery of operation is therefore delayed and temperature rises inside the storage unit. Furthermore, when the refrigeration unit is forced to stop due to defrosting, the frost will melt. However, not all of the melted frost will become drain water to be discharged to the outside of the storage unit during stabilized cycle operation, and a portion of it will remain in the storage unit as water vapor. In addition, we observed that this water vapor will freeze as the temperature of the evaporator decreases after the restart of operation, causing the former state to occur again.

(2) Lower limit control of the evaporation temperature

*2: Overheat: The refrigerant flowing inside the evaporator absorbs heat and successively changes to the state of evaporation. During this process, flow continues with fluid and evaporation being mixed, while temperature remains constant at the evaporation temperature. When all is evaporated, saturated vapor is generated, and as heat absorption continues, the temperature will rise once again. The value indicating the temperature rise from the evaporation temperature is referred to as overheat.

As mentioned in the previous section, we observed that the formation of frost on the evaporator that accompanies a decrease in the circulating air temperature inside the storage unit will grow from the upper portion to the bottom portion and eventually result in blockage, and that defrosting alone is insufficient to limit the amount of frost formation.

In general, the most effective method of implementing heat exchange for the evaporator is to utilize latent heat, and it is desirable to have stable operations in a state of small overheat. Therefore, it is effective to implement cooling inside the storage unit at an evaporation temperature that does not cause severe growth in the formation of frost, and it is considered that the most important factor in determining the growth of frost formation is the adjustment in the level of the evaporation temperature of the refrigerant.

By verifying growth in the formation of frost, we learned that the temperature with the most rapid growth of frost on the surface of the fins of the evaporator (frost formation temperature) is around −4.5 °C. In conventional units, the evaporator is set to −5.5 °C, and thus internal cooling proceeds creating a stable low temperature for the inside of the storage unit. In addition, frost forms over the entire surface of the evaporator fins, producing an even lower surface temperature for the evaporator. As a result of this, we were able to verify that the surface temperature drops below the frost formation temperature, thus causing growth in frost formation to accelerate and eventually creating a state of blockage for the fins on the air intake side.

Conventionally, heat exchange during cooling was effectively implemented with efficiency proportional to the temperature difference between the evaporation temperature and air intake temperature, but we performed an experiment to verify what would happen when raising the evaporation temperature by 2 °C, thus setting the temperature at −3.5 °C, which is higher than the frost formation temperature. The result of this experiment confirmed that the formation of frost neither spread throughout the entire surface, nor caused blockage of the fins. On the contrary, initial cooling was implemented successfully up to the point of stabilized cooling. Furthermore, our results showed that there was likewise no blockage of the fins during restoration of cooling after replenishing, and that the unit was also able to achieve a shorter completion of cooling time. This result was achieved because the amount of frost formation was decreased, while the heat exchange efficiency of the evaporator was comparatively increased.

Based on the results of this experiment, we readjusted the evaporation temperature level to -3.5 °C. By suppressing the lower limit of the evaporation temperature, we were able to reduce the amount of frost formation.

4.4 Evaluation results

As mentioned thus far, we implemented proper control of the cooling heat load, optimized operation control and carried out measures against frost formation to meet environmental conditions that included an ambient temperature of 40 °C and relative humidity of 75%. We were able to complete the restoration of cooling after replenishing in 13.5 hours, thus beating our target of 14 hours.

5. Postscript

We have successfully developed a cooling technology for global vending machines that is compatible with the high-temperature high-humidity environments characteristic of our target overseas markets.

This development enabled us to identify problems such as the increase in load due to large temperature differences between the ambient temperature and the temperature inside the storage unit, as well as the large impact of the phenomenon of frost formation generated in high-humidity environments. By taking appropriate measures, we have achieved our development goals.

In the future, we plan to continue our development efforts, aiming at not only achieving targets for cooling time under high-temperature high-humidity environments, but also at attaining further enhancements in operation stability and efficiency.

Supplemental Explanation

Supplemental explanation 1 Ejector

p.153, 158

An ejector is a fluid pump that sprays fluid such as steam from a nozzle to apply a negative pressure to the nozzle outlet in order to suck in other types of fluid.

Ejectors have such advantages as effective energy savings in water heaters or the expansion mechanism of refrigeration units used in car air conditioning systems, as well as facilitate easy maintenance in the pump mechanism used in equipment such as vacuum chucks and condensers for steam turbine systems. They are thus used in various types of applications.

The operations of an ejector are divided into three processes as shown in Fig. 1.

(1) Nozzle based acceleration and decompression of the driving flow

The nozzle works to restrict, accelerate and decompress the high-pressure driving flow. The conventionally used expansion valve suffered from energy loss caused by swirling that was generated by decompression via spraying from the orifice (restricting hole) as shown in Fig. 2.

(2) Driving flow based suction and mixing

The driving flow that is sprayed from the nozzle outlet becomes a negative pressure against ambient pressure based on the same principles as atomizers, resulting in the suction flow being drawn in and mixed.

(3) Diffuser based deceleration and pressurization

As the flow passage cross sectional area in the diffuser (expanding tube) expands, the velocity of the flow decreases and the pressure increases with converting kinetic energy into pressure energy.

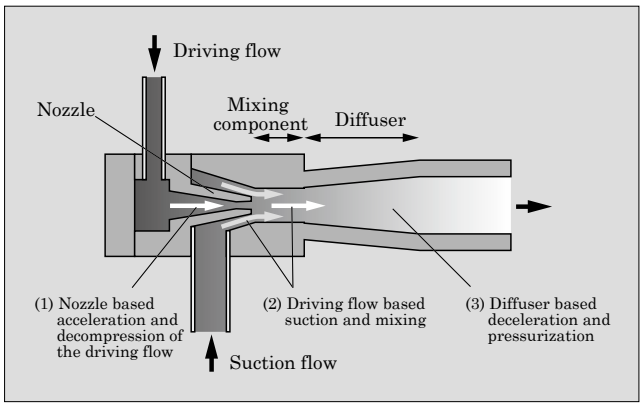


Fig.1 Operations of ejector

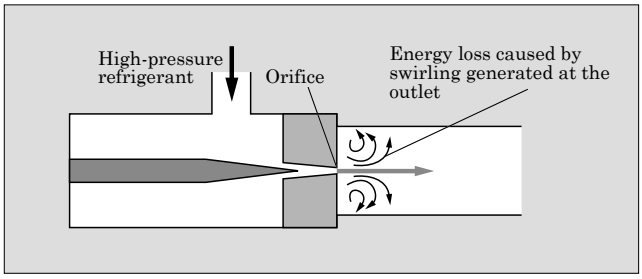


Fig.2 Swirling generated in conventional expansion valves

Programmable Display with Advanced User-Friendliness and Network Utilization "MONITOUCH V9 Advanced"

KOFUJI, Hiroyuki* **ISSHIKI, Takahiro*** **NAKANISHI, Takuya***

With greater proliferation of smartphones and tablets, now anyone can own such a device. These mobile devices continue to grow more advanced in terms of functions such as gesture control and Internet connectivity technologies.

There is a growing demand even in the industrial field for devices with the same operability as consumer mobile devices as well as remote monitoring and control that uses smartphones. For this reason, we have developed "MONITOUCH V9 Advanced," a programmable display that ensures the high level of quality required by the industrial field while maintaining the same operability as consumer devices and incorporates the latest network technologies.

1. Features

The "MONITOUCH V9 Series" lineup consists of three types of products to meet a variety of needs.

(a) "MONITOUCH V9 Lite"
The basic model, which offers basic performance.

(b) "MONITOUCH V9 Standard"
This model features added multimedia functions to provide more advanced functionality.

(c) "MONITOUCH V9 Advanced"
In addition to multimedia functions, this model comes equipped with capacitance-type touch switches and a wide LCD.

This document describes MONITOUCH V9 Advanced, the most advanced product in the lineup. The product's external appearance is shown in Fig. 1, while its specifications are listed in Table 1.

Fig.1 "MONITOUCH V9 Advanced"

Table 1 "MONITOUCH V9 Advanced" specifications

Item		Specification	
Type		V9101i WRLD	V9071i WRLD
Power supply	Rated voltage	24 V DC	
	Instantaneous power failure time	Within 1 ms	
	Power consumption	27 W or less	22 W or less
Temperature environment	Operating ambient temperature	0 to 50 °C	
	Operating ambient humidity	85% RH or lower (no dew condensation)	
Dimensions	W×H×D (mm)	278.5×198.5 ×54.4	201.6×147.6 ×60.3
Display memory (FROM)		64 MB	
Backup memory (SRAM)		800 KB	
Display specifications	Resolution	1,024×600	800×480
	Inches	10.1	7.0
	Backlight	LED	
	Backlight life expectancy	50,000 hours	100,000 hours
Touch switch specifications		Capacitance-type	
External interfaces	D-SUB	1 CH	–
	Modular	2 CH	
	SD card	1 slot	
	Ethernet	2 CH	
	Wireless LAN	1 CH	
	USB	Type A, Type mini-B	
	Audio output	1 CH	–

MONITOUCH V9 Advanced offers the following features:

(a) Functionality to support VPN/routing operation
(b) Capacitance-type touch switches
(c) Rich interface

MONITOUCH V9 Advanced offers 3 total channels of Ethernet*1 ports (wired and wireless), which can be used according to the application.

* Development Department, Hakko Electronics Co., Ltd.

*1: Ethernet is a trademark or registered trademark of Fuji Xerox Co., Ltd.

2. Underlying Technology

2.1 Functionality to support VPN and routing operations

VPN is a virtual network in which a virtual private line is established over the Internet, eliminating the need to install a new physical line. The MONITOUCH V9 Series features a built-in VPN compatibility function, making it easy to perform remote monitoring and control over a VPN server. Figure 2 shows an example of the architecture of a remote monitoring system.

In order to perform remote monitoring using conventional functionality, users had to prepare dedicated VPN routers and obtain and configure global IP addresses. The MONITOUCH V9 Series provides functionality to support VPN, hence VPN routers are no longer required. Therefore, no network skills are required to configure the VPN, and remote monitoring and control can be performed easily with existing equipment.

In addition to conventional functions such as monitoring and control using programmable controllers or network cameras, MONITOUCH V9 Advanced features built-in functionality to support routing for VPN. This allows for remote monitoring and control even from PCs.

MONITOUCH V9 Series has been designed with security in mind, and all communications between the unit, PCs, and VPN servers are encrypted.

2.2 Capacitance-type touch switches

On the resistive-type displays often used in the past, the operation position is detected by directly pressing a transparent resistance film opposite the transparent electrodes installed on the panel surface with a finger or a pen. Direct pressure needed to be applied to electrodes, causing electrode deterioration and reducing operability.

Capacitance-type displays detect the operation position by sensing changes in electrostatic capacity. Operation is possible by merely bringing a finger or the like close to the display, and there is no need to directly touch the electrodes. Therefore, glass or other materials can be placed over the operating surface, and no mechanical stress is applied to the electrodes. Furthermore, this technology can be operated with a light touch, allowing light gesture controls such as pinching in and out (Fig. 3).

Having these features, when compared with resistive-type displays, capacitance-type displays offer improved panel operability and a mechanical service life of approximately 1 to 10 million operations, which is at least ten times longer. Additionally, capacitance-type displays allow for both text entry and multi-point operation, whereas resistive-type displays do not allow for both (Table 2).

However, capacitance-type displays are sensitive to changes in the usage environment, and they require improved noise resistance and incorrect input measures. Hence, they control the operation at error detection with a software filter, and determines the level of field noise and provides periodic corrective action to keep up with environmental changes.

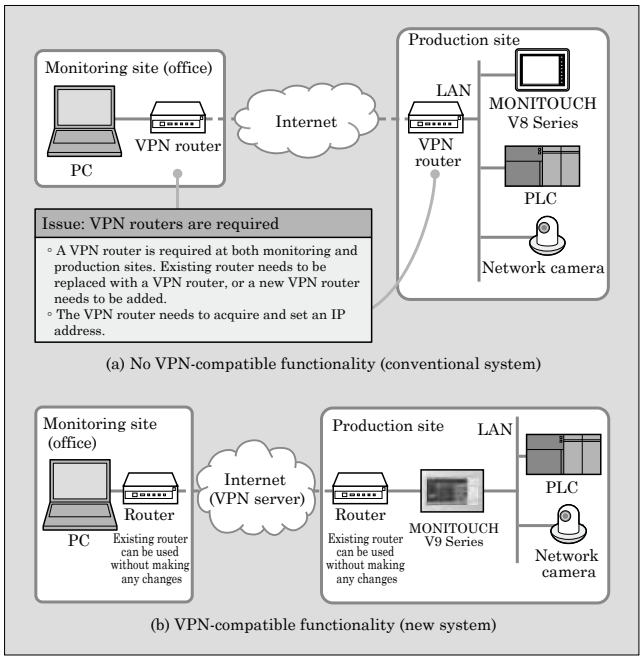


Fig.2 Example of building remote monitoring system

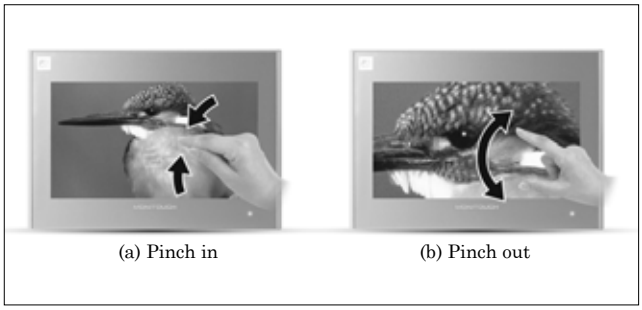


Fig.3 Gesture control

Table 2 Function comparisons for each type

	Analog resistive-type	Matrix resistive-type	Capacitance-type
Keystroke life expectancy	△ (Approximately 1 million operations)	△ (Approximately 1 million operations)	○ (10 million operations or more)
Text entry	○	× (Via electrode grid)	○
Multi-point operation	△ (Center point pressing)	○	○
Detection sensitivity	△ (Requires pushing pressure)	△ (Requires pushing pressure)	○

○ : Best, △ : Having room for improvement, × : Not acceptable

3. Global Expansion

MONITOUCH V9 Advanced is aimed for global expansion, and conforms to CE Marking (EMC), UL standards and KC standards. It already conforms to Japanese, US, Canadian, European and South Korean radio wave laws, and we are considering obtaining certification under the radio wave laws of additional countries, with the goal of expanding sales regions.

Launch time

April 2015

Product Inquiries

Development Department, Hakko Electronics Co., Ltd.
Phone: +81-76-274-5268

Global Standard Temperature Controller "PXF Series"

HAGIOKA, Nobukazu*

Fuji Electric provides instrumentation and control systems and measuring equipment to contribute to energy saving, safety and security. Of these, our temperature controllers have been rated highly by customers, particularly our high quality "PXR Series" which offers superior cost performance. Over 3 million units have been sold worldwide to date.

Providing the same user-friendliness as our core product PXR Series, the "PXF Series," further expands the functionality of the multi-functionality type "PXG Series," and is particularly suited to the global market (see Fig. 1).

1. Fuji Electric's Temperature Controller Lineup

Fuji Electric offers a wide variety of temperature controllers classified by application and price range (see Fig. 2). The lineup consists of controllers which can be used in a wide range of applications, from compact devices to different types of manufacturing equipment and pressure controllers, satisfying each customer's needs ranging from on/off control to cascade control.

Table 1 lists the functional comparison between the PXF Series, PXR Series and PXG Series.

The "PXF Series" combines the features of the core PXR Series with the multi-functionality type PXG Series and have high-speed performance and high functionality to support the global market.

Fig.1 "PXF Series"

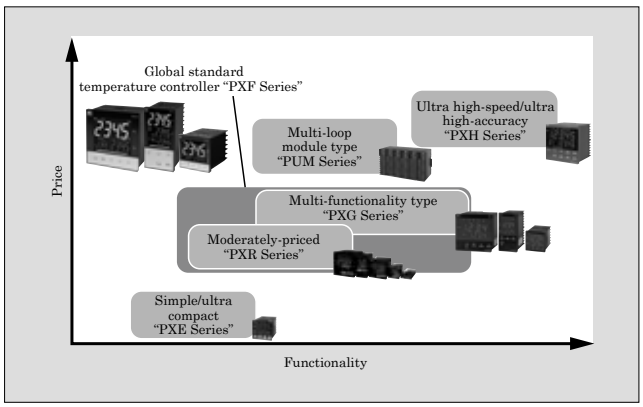


Fig.2 Temperature controller lineup and positioning

2. Features and New Functions of "PXF Series"

2.1 Features

(1) High-speed input sampling cycle and control calculation cycle

The input sampling cycle is reduced to 50 ms, one-tenth that of the PXR Series, while the control cycle is reduced to 100 ms, one-fifth that of the PXR Series. Furthermore, indication accuracy is improved from ±0.5% to ±0.2% compared with the PXR Series at a range of 0 °C to 850 °C with resistance temperature detector input. This ensures finer control and helps to improve productivity and processing quality in systems.

(2) The industry's smallest size class

Compared to previous products, the unit is approximately 25% smaller. The unit boasts the industry's smallest size class (58 mm depth behind a panel), helping to make systems more compact.

(3) Universal input

Merely changing parameters allows a user to use any input among thermocouples, resistance temperature detectors, voltage, current and mV DC. This can reduce temperature controller inventory for maintenance use, and supports sudden sensor changes on site.

2.2 New functions

(1) 2-degrees-of-freedom PID control function

Conventional PID control had issues where tuning to shorten the startup time of heating up facilities would increase overshoot, while tuning to suppress overshoot would increase the startup time. The PXF Series adopts a 2-degrees-of-freedom PID control function that changes the PID control amount as the process value approaches a set value, allowing it to short-

* Industrial Infrastructure Business Group, Fuji Electric Co., Ltd.

Table 1 “PXF Series” functions

Series name	PXF Series	PXG Series	PXR Series
Input sampling cycle	50 ms	200 ms	500 ms
Control cycle	100 ms	200 ms	500 ms
Indicator	11-segment characters 4-color display (PV displayed in white) Wide viewing angle/high contrast MVA LCD panel	7-segment characters Red and green High brightness LED display	7-segment characters Red and green High brightness LED display
User assignment key	○	○	–
Shift key	○	–	–
2-degrees-of-freedom PID control	○	–	–
Electric valve control	□*1	□	–
Simple power monitoring function	○	–	–
Operation time alarm function	○	–	–
Ramp SV	○	○	–
Ramp/soak function	○ 64 step	○ 32 step	□ 16 step
Loader communication port	○ USB power feeding	○ Mini-jack (no power feeding)	–
Alarm/event output	□ Max. three points (max. five points*1)	□ Max. five points	□ Max. three points
Alarm/event output types	400 or more	82	31
Event input	□ Max. five points*1	□ Max. five points	□ Max. two points
Event input types	50 or more	48	12
Heater current monitoring function	□ Max. 100 A	–	–
Heater disconnection alarm	□ Max. 100 A	□ Max. 50 A	□ Max. 50 A
RS-485 communication port	□ Max. 115.4 kbits/s	□ Max. 19.2 kbits/s	□ Max. 9.6 kbits/s
Programless communication	Compatible with Siemens-S7 and Mitsubishi Q Series*1	–	–
Wireless loader	Bluetooth*2,3	–	–
Depth (behind panel)	58 mm	78 mm	78 mm

○: Standard function, □: Optional function
*1: Market launch in April 2015, *2: Development under consideration, *3: Bluetooth: A trademark or registered trademark of Bluetooth SIG, Inc.

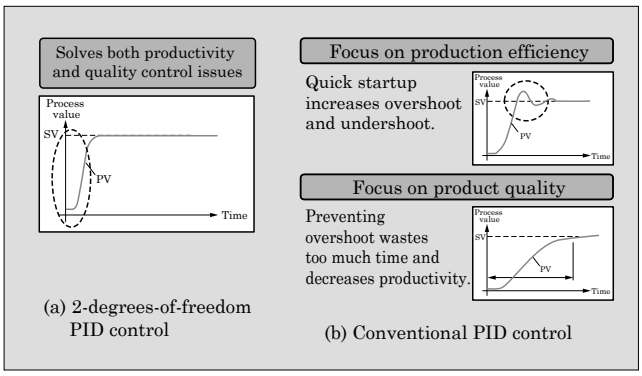
en the startup time, while suppressing overshoot. This solves both productivity and quality control issues, and is effective in optimizing operations and saving energy (see Fig. 3).

(2) Highly visible indicators

The unit is equipped with an MVA LCD panel, which boasts a wide viewing angle and high contrast, and display a current temperature (PV) in white for increased visibility.

It employs an 11-segment display for the upper and lower text display areas to make text easier to read and improve visibility. It has the industry’s largest character height for an LCD display (PXF4: 15.3 mm, PXF5: 18.1 mm, PXF9: 26.0 mm) to help users monitor the temperature from far away (see Fig. 4).

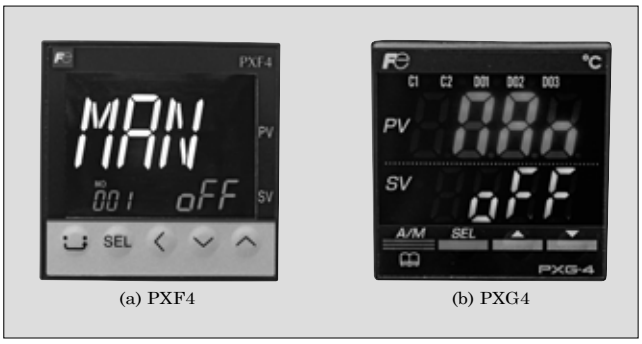
In addition to displaying the PV and SV (setting temperature), the unit features an auxiliary display to show time, electric energy or bar graphs (bar graph display is available only on PXF5 and PXF9).



(a) 2-degrees-of-freedom PID control

(b) Conventional PID control

Fig.3 2-degrees-of-freedom PID control function



(a) PXF4

(b) PXG4

Fig.4 Indicator

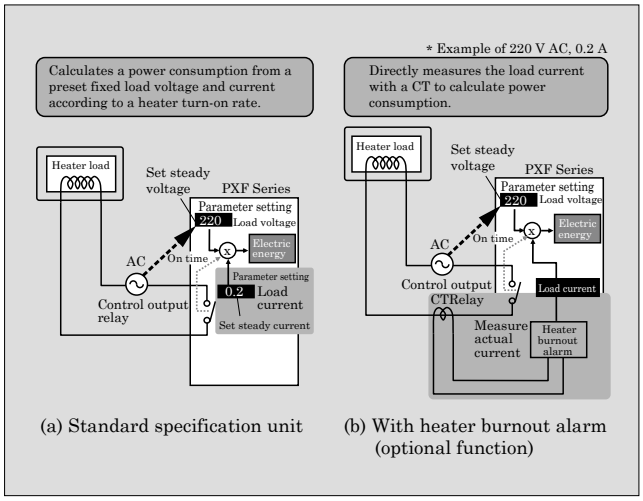
The auxiliary display can display a number corresponding to each parameter. These parameter numbers can be used when exchanging information during remote support over telephone, allowing users to accurately and quickly understand applicable parameters.

The indicator is color-coded by function and application with four colors (white, green, red, orange) to promote safe operation.

(3) Simple watt-hour metering function

The unit allows for system power consumption to be easily monitored, supporting the energy conservation efforts of users.

It features a simple watt-hour metering function that can monitor the power consumption of controlled heaters, for the first time in the industry. This function supports relay control outputs only. It can be used to evaluate energy saving effects on site and to preliminarily evaluate of equipment power consumption in an assembly manufacturer (see Fig. 5).



(a) Standard specification unit (b) With heater burnout alarm (optional function)

Fig.5 Simple watt-hour metering function

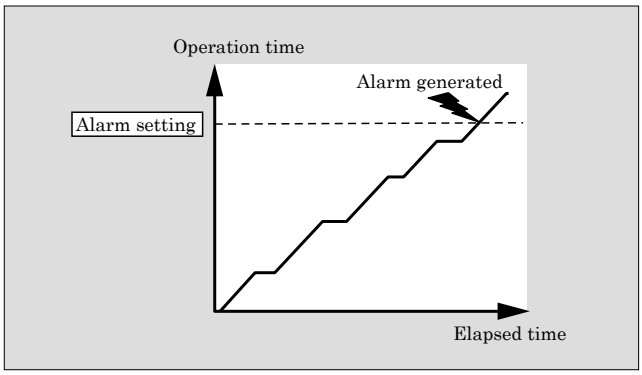


Fig.6 Operation time alarm function

(4) Operation time alarm function

The unit notifies users of maintenance and inspection timing, supporting preventive maintenance for systems.

It includes the function that sounds an alarm when the operation time of the temperature controller itself reaches a set time. It can be used for preventive maintenance of facilities by setting the alarm timing according to the shortest service life of maintenance parts. This can help to reduce system costs as there is no need to install a preventive maintenance timer (see Fig. 6).

Launch time

November 2014

(April 2015 for some functions)

IEC Standard Compliant 7.2-kV Switchgears

FUKUDA, Yoshitaka* **KITAMURA, Takaaki‡** **IWAMOTO, Satoshi‡**

Switchgears are devices capable of safely opening and closing circuits, while monitoring the status of such operations. In the global market, switchgears should be compliant with the IEC standard (IEC 62271-200). This standard enhances concept of safety, for example, classifications of structure of service continuity and protection of surrounding persons when fault occurs or in maintenance. Furthermore, the Japanese standards JEM also tends to align with the IEC standards.

In light of this, Fuji Electric has developed and released IEC standard 7.2-kV switchgears for the global market.

1. Features

Figure 1 shows the external appearance of the 7.2-kV switchgear, and Table 1 describes its main specifications. The switchgear houses a vacuum circuit breaker (VCB) or vacuum magnetic contactor (VMC). Figure 2 shows the external appearance of the equipment.

1.1 Safety

(1) Mechanical interlock system

The switchgear is designed to incorporate interlock by means of a mechanical mechanism in order to prioritize the safety of people.

It allows the front door to open only when the circuit breaker (VCB, VMC) is in the disconnected/test position and allows the rear cover to open only when the earthing switch is in the "closed" position (non-charge via the cable-side earth). In addition, the earthing switch cannot be operated simultaneously with the circuit breaker, and the circuit breaker can be inserted and withdrawn only when it is in the "open" position.

(2) Safety during inspection

The IEC standard stipulates functional categories of loss of service continuity (LSC) according to a power shutdown area during inspections. A category based on loss of service continuity is adopted in place of the conventional type of category, which is based on the partition structure of metal-clad type (MW) and compartment type (CW).

Developed switchgear is in compliance with the "LSC2B-PM" class that can be safely inspected during service condition. In order to carry out inspection safely, earthed metal shutters are adopted for the

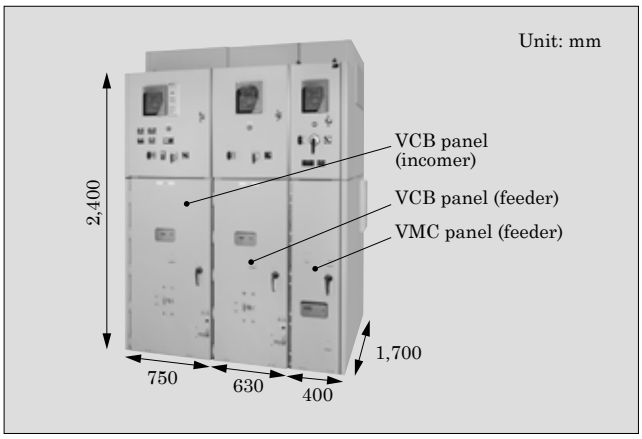


Fig.1 7.2-kV switchgear

Table 1 7.2 kV switchgear main specifications

Item	VCB Panel	VMC Panel
Model	VC-V6A	VC-VS6A
Applicable standards	IEC 62271-200	
Rated voltage	3.6/7.2 kV	
Rated bus bar current	2,500 A	
Rated current	2,000/1,250 A	200/400 A
Rated short-time withstand current	31.5/40 kA, 3 s	
Loss of service continuity (LSC)	LSC 2B-PM	
Internal arc classification (IAC)	AFLR, 31.5 kA, 1 s	

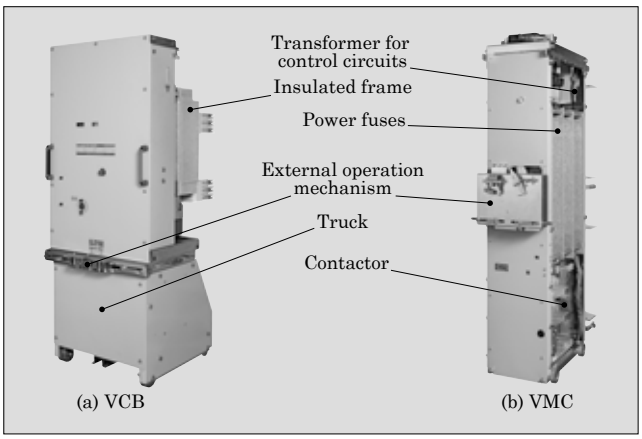


Fig.2 Switchgear housed equipment (VCB and VMC)

* Industrial Infrastructure Business Group, Fuji Electric Co., Ltd.
‡ Power Electronics Business Group, Fuji Electric Co., Ltd.

bushings of the circuit breaker, and the inside of the panel is configured with metal partitions for each circuit breaker compartment, bus bar compartment and cable compartment.

(3) Safety at internal arc fault

In the event of an internal arc fault, surrounding people face risk of harm associated with high-temperature gases and flying debris. The IEC standard stipulates individual classifications for human safety for the front (F), lateral sides (L) and rear (R) of the switchgear. Developed switchgear accessibility applies classes "AFLR" so that the safety area corresponds to the omnidirection of a distance of 300 mm from the switchgear (accessibility class A).

(4) Prevention of live part exposure via an insulated bus bar structure

In order to reduce the number of earth fault or short circuit accidents, the bus bar comes standard with an insulated coating, and the connection is protected with an insulated cover, thus providing the unit structure that ensures that the live part is not exposed.

1.2 Reduction in panel width and depth

In order to reduce the width of the VCB panel, we have developed an insulated frame that shortens the distance between VCB phases, and we also have achieved width and depth reductions for the panel by positioning the cable connection in the bottom section of the panel.

On the other hand, in order to reduce the width of the VMC panel, we arranged power fuses at the front and rear of the VMC unit, while also arranging a transformer for control circuits in the upper section and the switch component in the lower section of the unit. Furthermore, we reduce the main bus bar insulation distance by applying an insulation coating and insulation barrier, allowing the panel to reduce in width and have the same depth as that of the VCB panel.

In addition, we can offer both the mechanisms of the mechanical latching type and electromagnetic latching type as VMC operation systems in the same size.

1.3 Truck type circuit breaker (VCB, VMC)

We have adopted the truck type of the circuit breaker, which can be directly drawn in and out from the floor of substation without a lifter, enabling to conduct shutdown maintenance efficiently.

1.4 Plated steel and riveted structure frame

Considering the environment, we have adopted anti-corrosion special aluminum alloy plated steel for the frame to reduce painting materials. Furthermore, we have also adopted thin steel plates with rivet assembly structure for lightweight and recycle.

2. Background of Technologies

Figure 3 shows the internal structure of VCB and VCS panel.

2.1 External operating mechanism unit

The IEC standard stipulates that the circuit breaker shall be possible to be drawn in and out from a switchgear by the operation from outside the switchgear when the door is closed. To meet this requirement, we have developed an external operating mechanism unit and mounted it to the circuit breaker. The unit employs a feed screw system to easily draw the circuit breaker in and out from the switchgear. The earthing switch also adopted a structure that enables switching operation with the front door closed.

Moreover, the switching indicator of the circuit breaker can be monitored visually from outside the front door through a tempered glass inspection window.

2.2 Countermeasures against internal arc fault

In case of internal arc fault, arc energy should cause sharp spikes in internal pressure and temperature. Therefore, we have configured the unit with a pressure relief device (flapper) for each circuit breaker compartment, bus bar compartment and cable compartment in order to suppress pressure rise and have also adopted a structure for safely releasing pressure in a manner that causes no harm to persons in the vicinity of the panel.

We have utilized simulations to conduct pressure analysis and strength analysis in order to study the internal pressure rise at internal arc fault. Figure 4 shows an example of the pressure analysis and strength analysis for the cable compartment. The figure shows the pressure distribution right after an internal arc fault. The highest pressure is in the vicinity of the arc (indicated in red). By combining the pressure analysis and strength analysis in the study, we were able to calculate the optimal pressure relief areas of each compartment and determine a frame struc-

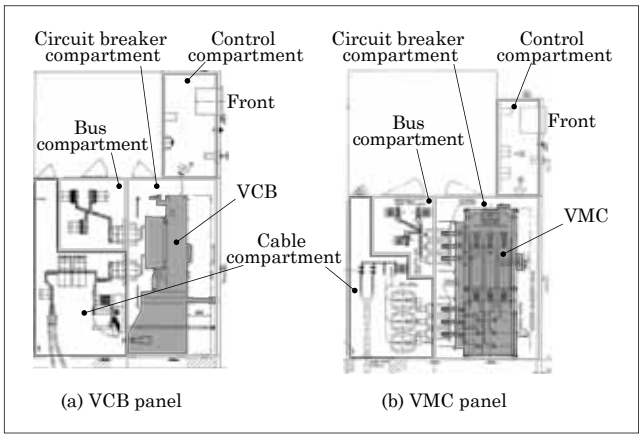


Fig.3 Feeder internal structural diagram

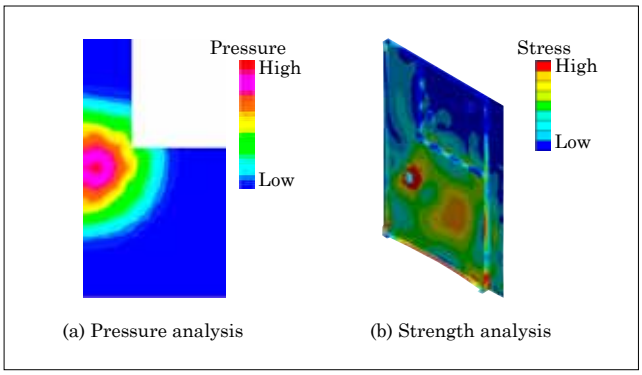


Fig.4 Example of pressure analysis and strength analysis at internal arc fault

ture to withstand pressure increase at the internal arc fault.

2.3 Internal arc test

The internal arc test was implemented at a public testing institution. The IEC standard specifies detailed provisions regarding the requirements of internal arc testing including the arrangement of simulations such as those related to the walls and ceiling of the substation. Figure 5 shows the conditions of an internal arc test.

We carried out an internal arc withstand test for each circuit breaker compartment, cable compartment and bus bar compartment and confirmed that the switchgear sufficiently satisfies safety requirements in the event of an internal arc fault.

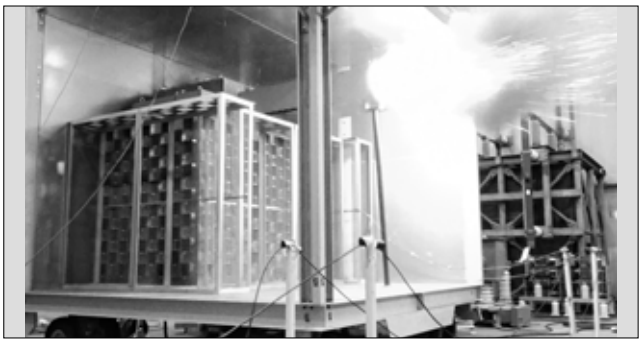


Fig.5 Internal arc test

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Geared Motors "MGX Series" and "MHX Series," and Brake Motor "MKS Series," Which Meet Top Runner Standards

TACHI, Norihiro*

We have developed and launched the "MGX Series" and "MHX Series" geared motors, and the "MKS Series" brake motors. These products meet Top Runner Standards, and are smaller and quieter than conventional products.

1. Features

1.1 Motors conform to Top Runner Standards

MGX Series and MHX Series geared motors, and MKS Series brake motors have the same electrical characteristics as Fuji Electric's Top Runner motor "Premium Efficiency Motor." These products meet premium efficiency (IE3) standards with three ratings[*1].

1.2 "MGX Series" and "MHX Series" geared motors

We offer two series of geared motors: the MGX Series, which consists of motors that have parallel rotating and output shafts, and the MHX series, with motors where the shafts are perpendicular. Figure 1 shows the external appearance of each series, and Table 1 shows their main specifications. Geared motors incorporate gears (speed reducer) at the output side. These motors are thus used in applications requiring space saving and large torque generation at a low rotational speed, such as conveyors or car washes.

(1) Compatibility with conventional products

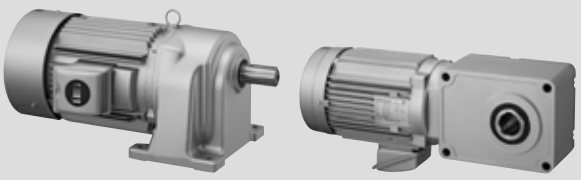
MGX Series and MHX Series motors are given the same mounting dimensions as conventional products. The output shaft allowable OHL (overhang load) is kept at the same level or higher. In addition, models with brakes have the same braking characteristics (torque and operating time).

(2) Improved environmental resistance

Although high efficiency motors generally have a larger starting current, our geared motors are designed to have a maximum starting current 130% or less that of conventional products, similar to our premium efficiency motors. This made it possible to minimize the effect on peripheral equipment. We have also reduced their acoustic noise a maximum of 5 dB compared with conventional products.

(3) Motors conform to EC directives

We designed the standard specification to conform to EC directives (low voltage directives).



(a) "MGX Series" (Parallel shaft type)

(b) "MHX Series" (Perpendicular shaft type)

Fig.1 Geared motors

Table 1 "MGX Series" and "MHX Series" main specifications

Item	Specification	
Series (type)	MGX Series (Parallel shaft type)	MHX Series (Perpendicular shaft type)
Housing structure	Totally enclosed fan cooled type	
Output	0.75 to 7.5 kW	0.75 to 2.2 kW
Number of poles	4P	
Rating	S1 (continuous)	
Gear ratio	750 W: 1/3 to 1/500 1.5 to 2.2 kW: 1/3 to 1/300 3.7 to 5.5 kW: 1/3 to 1/120 7.5 kW: 1/3 to 1/80	750 W: 1/7 to 1/200 1.5 to 2.2 kW: 1/7 to 1/120
Gear lubrication method	Grease lubrication	
Thermal class	155 (F)	
Protection rating	IP44	
Color of coating	Silver	
Motor efficiency class	IE3/IE3-IE3 at 200/200-220 V, 400/400-440 V, 50/60 Hz	

1.3 "MKS Series" brake motors

Figure 2 shows the external appearance of the MKS Series, and Table 2 lists its main specifications. Brake motors are structured with a disc-type brake attached to the opposite load side of the motor. They are thus used in applications requiring reliable stopping during an emergency, such as in elevators and hoists.

* Power Electronics Business Group, Fuji Electric Co., Ltd.

*1: Three-ratings refer to 200 V/50 Hz, 200 V/60 Hz and 220 V/60 Hz. For 1.5 kW 6-pole, 11 kW 4-pole and 15 kW 4-pole brake motors, 200 V/50 Hz and 220 V/60 Hz models comply with IE3, while 200 V/60 Hz model comply with IE2.

Fig.2 “MKS Series” brake motors

Table 2 Main specifications of “MKS Series”

Item	Specification
Housing structure	Totally enclosed fan cooled type (indoors)
Output	4P: 0.75 to 15 kW, 6P: 0.75 to 3.7 kW
Rating	S1 (continuous)
Thermal class	155 (F)
Protection rating	Motor section: IP44, brake section: IP20
Color of coating	Munsell N1.2 (black, no gloss)
Braking method	Non-excitation actuated type
Brake torque	150/180% of rated torque (50/60 Hz)
Motor efficiency class	4/6P-7.5 kW or lower (excluding 6P-1.5 kW): IE3/IE3-IE3 at 200/200-220 V, 50/60 Hz 4P-11 kW or higher and 6P-1.5 kW: IE3/IE2-IE3 at 200/200-220 V, 50/60 Hz

(1) Compatibility with conventional products

The MKS Series motors have the same mounting dimensions as conventional products. They also have the same braking characteristics (torque and operating time). The popular loosened brake handle is provided as standard equipment.

(2) Improved environmental resistance

Our brake motors were designed to have a maximum starting current 130% or less that of conventional products, similar to geared motors. This made it possible to minimize the effect on peripheral equipment. We have also reduced acoustic noise a maximum of 5 dB compared with conventional products.

1.4 Energy saving effect

A 15-kW 4-pole product is used in the example below to calculate the energy saving effect of replacing a conventional product with the developed model. Assuming an operating time of 4,800 hours per year, power consumption would decrease from approximately 80,000 kWh to 78,000 kWh. This adds up to an energy saving effect of around 2,000 kWh, or a savings of around 32,000 yen when converted into power fees (at a rate of 16 yen per kWh).

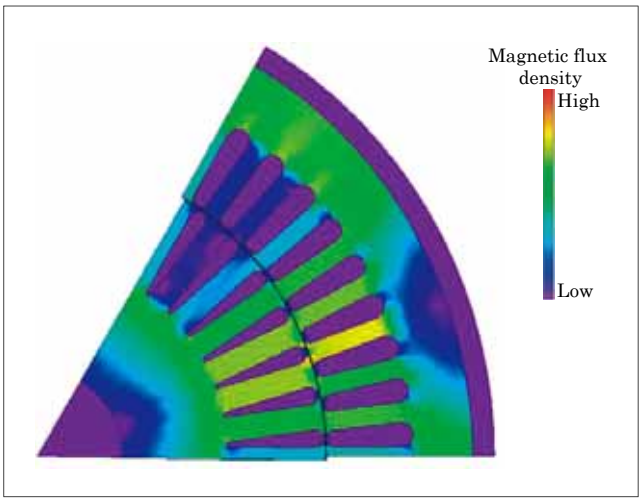


Fig.3 Example of iron core magnetic flux density distribution

2. Underlying Technologies

The ratio of loss generated in each part of the motor varies according to the output and number of poles. It is divided into copper loss (primary side and secondary side), iron loss, mechanical loss and other stray load loss. It is important to reduce copper loss and iron loss because they account for around 50% and 30% of total loss respectively[1]

Increasing the size of the core groove for the conductor is effective in reducing copper loss caused by electric resistance of the conductor. However, increasing the size of the core groove increases the magnetic flux density of the core, causing more iron loss. The finite element method is used to optimize the core groove size and shape to reduce total loss while considering the balance between each type of generated loss and characteristic. As shown in the analysis example in Fig. 3, the magnetic flux density distribution is homogenized. We also utilized a magnetic steel sheet with low iron loss in an attempt to further reduce loss.

A fan is attached on the opposite load side in order to cool the motor. A mechanical loss is generated as it rotates. We have revised the shape of the fan to reduce mechanical loss and wind noise.

References

(1) TACHI, N. et al. Fuji Electric’s Top Runner Motor: Loss-Reduction Technology of “Premium Efficiency Motor”. FUJI ELECTRIC REVIEW 2015, vol.61, no.1, p.31-35.

Launch time

"MGX Series" and "MHX Series": June 2014
"MKS Series": August 2014

Product inquiries

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Standby Power Supply Mini-UPS “UX100 Series”

IWAI, Kazuhiro*

Industrial equipment and personal computers often utilize, as a backup power supply, an uninterruptible power system (UPS) of continuous commercial power feeding system, which is low cost and highly efficient. In light of this, Fuji Electric has developed the small-capacity continuous commercial power feeding UPS “UX100 Series.”

The UX100 Series is compatible with the power supply monitoring function of the computer operating systems and comes standard with a universal serial bus (USB) based shutdown function. Furthermore, this model provides the selectable mode, which the conventional model does not have, that quickly changes it to battery operation when a failure occurs in the commercial power supply to reduce the variation of output voltage and continue stable power supply. Figure 1 shows the external appearance of the UX100 Series. The UX100 Series comes in a 500 VA model, 750 VA model and 1 kVA model, allowing the user to select a capacity that corresponds to operating conditions.

1. Continuous Commercial Power Feeding UPS

Figure 2 shows the circuit block diagram of a continuous commercial power feeding UPS. When the commercial power is supplied normally, the UPS directly outputs it to its load equipment, allowing the UPS to operate efficiently.

When a failure such as power outage occurs in the commercial power supply, the output of the battery is converted into alternating current by the inverter to supply power to the load equipment. In such a case, the output waveform may include a rectangular or sine wave, depending on the inverter.

Fig.1 “UX100 Series”

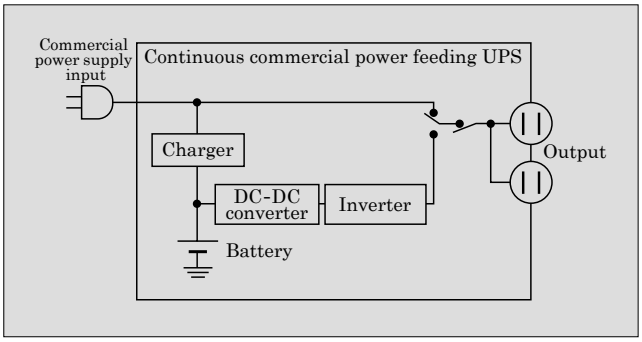

Fig.2 Circuit block diagram of continuous commercial power feeding UPS

2. Features of “UX100 Series”

The features of the UX100 Series are as follows.

- ○ USB based shutdown function
- ○ High-speed changeover to battery operation via high-sensitivity mode
- ○ Sine wave output during battery operation
- ○ DC start function
- ○ Available for vertical and horizontal placement

(1) USB based shutdown function

The UX100 Series comes with USB ports on the back of the unit. The unit supports power devices of human interface device (HID) using data communication with a USB port, and it can use the power supply monitoring function that comes standard in computer operating systems such as Windows*1. This function enables the unit to automatically shut down the OS or perform other operation according to the monitoring state of the UPS and the remaining battery capacity. Figure 3 shows the example of a USB based connection and personal computer display.

(2) High-speed changeover to battery operation via high-sensitivity mode

Continuous commercial power feeding UPS takes about 10 to 100 ms for the changeover time from the occurrence of failure in the commercial power supply until the start of battery operation. This changeover time is generally slow when the voltage drop level of

* Power Electronics Business Group, Fuji Electric Co., Ltd.

*1: Windows is a trademark or registered trademark of Microsoft Corporation.

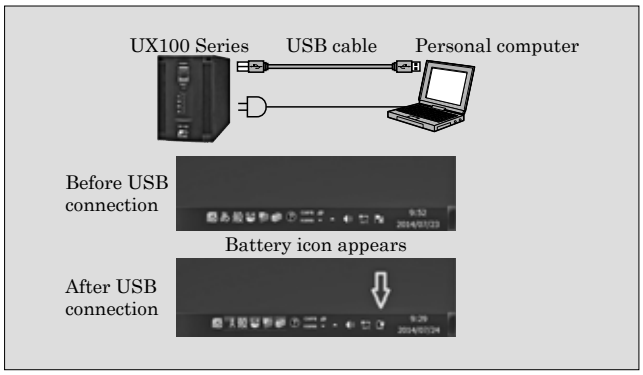

Fig.3 USB based connection example and computer display example

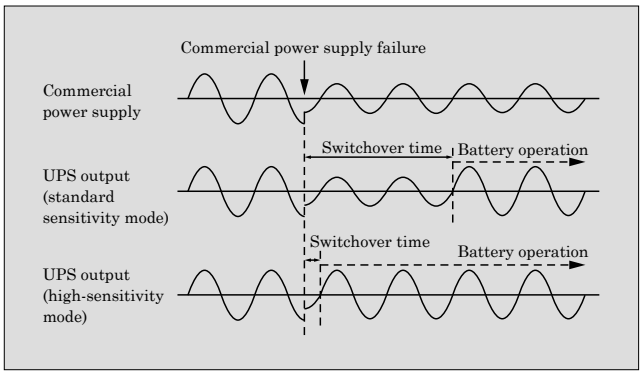

Fig.4 Changeover in standard sensitivity mode and high-sensitivity mode

the commercial power supply is small.

In addition to the conventional "standard sensitivity mode" for detecting failures in the commercial power supply, the UX100 Series comes with a "high-sensitivity mode" capable of even faster changeover times (see Fig. 4). High-sensitivity mode enables the unit to change to battery operation even when the voltage drops slightly. Users can select either of the two modes corresponding to the usage environment and load with the dip switch on the back of the unit.

(3) Sine wave output during battery operation

Some types of continuous commercial power feeding UPSs output rectangular waves during battery operation, thus making it necessary to check matching with the load equipment. However, the UX100 Series outputs a sine wave during battery operation, and as a result, it is unnecessary to check matching with the load equipment.

(4) DC start function

The DC start function, also referred to as battery start-up, starts the UPS to supply power to the load equipment from the battery when the commercial power is not supplied. This function enables the UPS to start supplying power to the load equipment even when a power outage continues. Changing the power frequency setting (50/60 Hz) needs to be performed using the dip switch on the back of the unit because it cannot set automatically without a commercial power supply.

(5) Available for vertical and horizontal placement

Table 1 Main specifications of "UX100 Series"

Item		500 VA model	750 VA model	1 kVA model
Operating system		Standby power supply system		
AC input	Rated voltage (voltage range)	100 V (80 to 117 V)		
	Number of phases	Single-phase two-wire, with ground		
	Frequency	50/60 Hz (automatic setting)		
	Max. input current (including cable charging breaking capacity)	6 A	9 A	12 A
AC output	Rated output capacity	500 VA/350 W	750 VA/525 W	1,000 VA/700 W
	Number of phases and wires	Single-phase two-wire, with ground		
	Output Voltage	80 to 117 V		
	Output waveform	Sine wave (during battery operation)		
	Output waveform distortion rate	During rectification load: 20% (during battery operation)		
	Output outlet	NEMA5-15R×4		NEMA5-15R×6
Battery	Battery type	Long life type sealed lead-acid battery		
	Backup time	3.5 minutes	5 minutes	3.5 minutes
Environment conditions	Ambient temperature	0 °C to 40 °C		
	Relative humidity	25 to 85% (non-condensing)		
	Audible noise	40 dB (A) or less		45 dB (A) or less
	Safety standard	UL1778		
	EMC	VCCI Class B		
Cooling system		Natural cooling		Forced-air cooling
Dimensions		W107×D308×H162 (mm)	W93×D395×H250 (mm)	W93×D395×H250 (mm)
Mass		5.6 kg	9.7 kg	10 kg

The UX100 Series can be placed both vertically and horizontally (see Fig. 5). To position it horizontally, the provided rubber feet must be attached to the unit.

(6) Specifications

Table 1 shows the main specifications of the UX100 Series.

3. Applications of "UX100 Series"

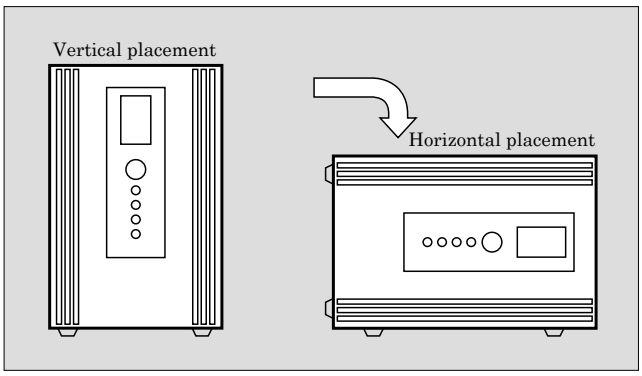

Fig.5 Vertical and horizontal placement

The UX100 Series can be used as a backup power supply for the following equipment and devices.

- ○ Personal computers and peripheral devices
- ○ POS terminals and change machines
- ○ Network equipment such as IP telephones, hubs and wireless LAN routers
- ○ Security equipment such as surveillance cameras
- ○ Various factory automation equipment and industrial equipment

Launch time

September 2014

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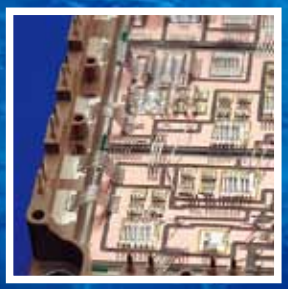

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