2004 Prize of the Chairman of ECCJ

Energy Conservation of Hydraulic Pumps with Pressure Interlocked Inverter Control System

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Energy Session

◎ **Keywords: Rationalization of conversion of electricity to motive power heat, etc. (Electric power application equipment, electric heating equipment, etc.)**

◎ Outline of Theme

Most of the production equipment is equipped with hydraulic pumps and, at one time, the inverter control was seen as an effective energy conservation way for those pumps. However, in a viewpoint of the cost effect and the work efficiency, it was introduced only to part of large pumps. In case of hydraulic pumps used at the processing and assembly lines, the inverter control has not been introduced, because their motors are as small as around 3.7 kW and the number of units is many. Nonetheless, we developed a pressure interlocked inverter system with the indices of "easy modification", "low cost" and "secure effect" and introduced it in bulk in a short time, which had been seen difficult till then, contributing to the energy conservation of the processing lines.

◎ Implementation Period of the Said Example

April 2002 – December 2003

● Project Planning Period (test and research)	April 2002 – March 2003
● Measures Implementation Period	April 2003 – December 2003
● Measures Effect Confirmation Period	April 2003 – February 2004

◎ Outline of Business Establishment

● Items Produced	Automobile parts (aluminum casting, magnesium alloy casting, resin forming, etc.) Transmission cases, delivery pipes, pistons, oil pumps, etc.

- No. of Employees 1386 (As of March, 2004)
- Annual Energy Usage Amount (Actual results for fiscal year 2003)

LNG	19.333 million Nm^3
LSA	2,416 kL
Electricity	105,169 MWh

◎ Outline of Target Facilities

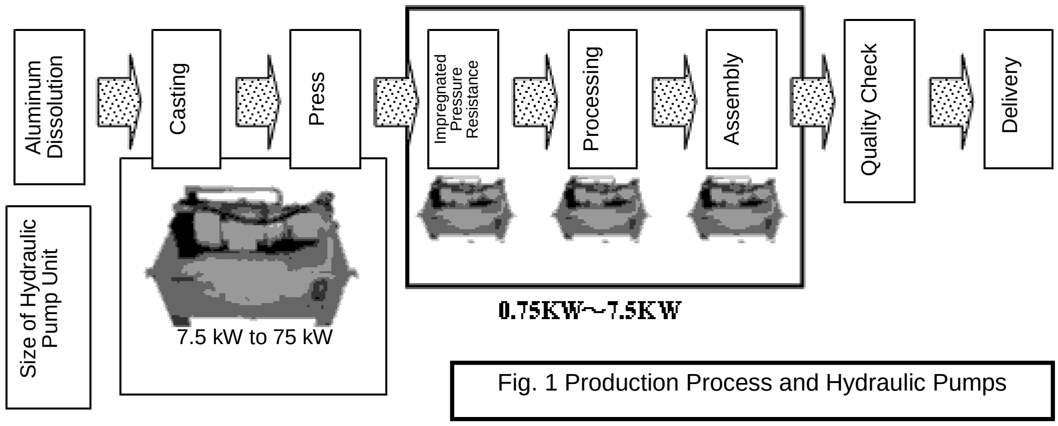


Fig. 1 Production Process and Hydraulic Pumps

1. Reasons for Theme Selection

The processing and assembly lines are by far the most in the ratio of the number of production facilities and the most equipment is equipped with hydraulic pumps. We used to install the inverter control as an energy conservation technique for the hydraulic pumps till a few years ago, but we did so only for the part of the pumps whose capacity is 7.5 kW or more due to the restriction of the cost effect. Especially, as for the hydraulic pumps in the processing and assembly lines, they were not supported by the energy conservation activities because their capacity was small and the number of the units was many. However, although their capacity was small, we could not neglect the electricity consumed by hundreds of them, so we decided to study the energy conservation for them anew.

Making the concept of the research and development “low cost, easy modification and secure effect”, we aimed to realize a short period mass quantity modification system to be applied to the processing lines, etc.

2. Understanding and Analysis of Current Situation

(1) Understanding of Current Situation

Of the net electricity consumed by the equipment of the processing and assembly lines, the ratio of the hydraulic pumps is as high as 56%. The net electricity consumption concerning the rated electricity of each motor is small, but, as the absolute number of the processing and assembly equipment is a lot, the total electricity consumption cannot be neglected.

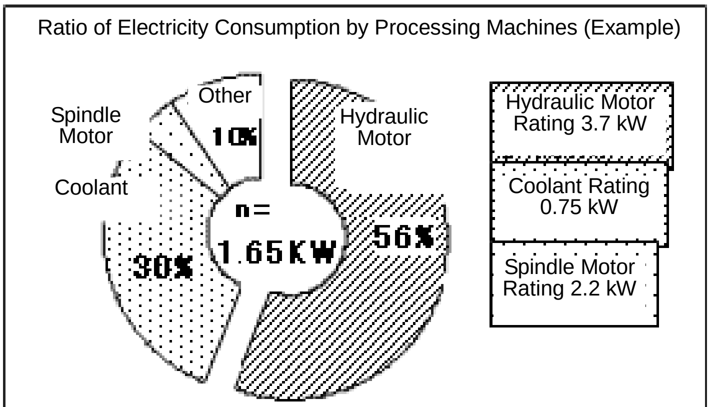


Fig. 2 Ratio of Electricity Consumption by Processing Machines

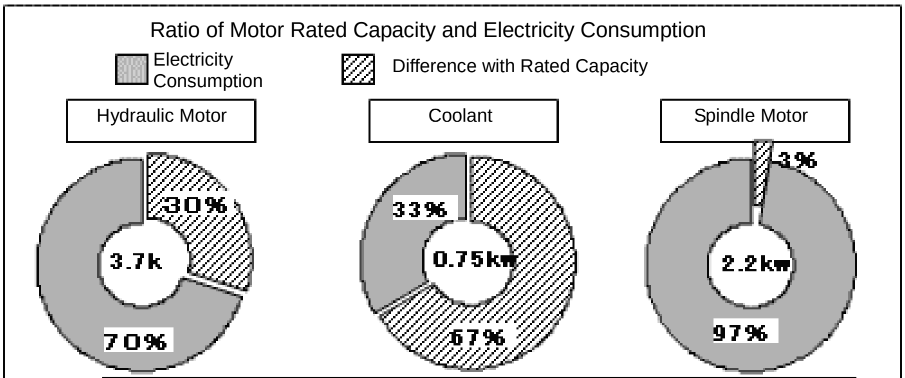
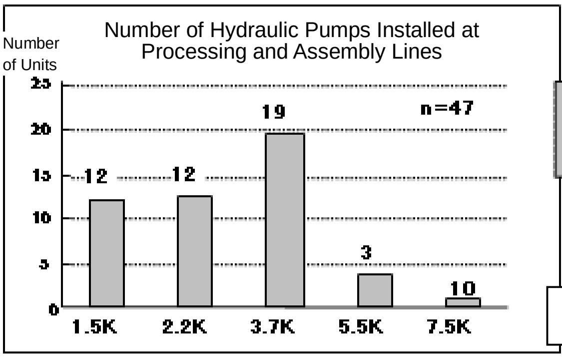


Fig. 3 Ratio of Motor Rated Capacity and Electricity Consumption



Yearly Total Electricity Consumption by Total Hydraulic Pumps of Processing and Assembly Lines

2,262 MWh

CO_2 Emission 235t

Fig. 4 Number of Hydraulic Pumps Installed at Processing and Assembly lines

(K : kW)

(2) Analysis of Current Situation

There are following energy conservation technologies for hydraulic pumps.

1) 1 cycle intermittent operation.

2) Revolution control by the inverter.

3) Change to the hydraulic unit “Eco Rich” made by Daikin.

4) Intermittent operation by the accumulator.

However, of the 479 hydraulic pumps installed to the processing and assembly lines, the pumps which were improved for the energy conservation are only about 32 units and no inverter control has been introduced to them.

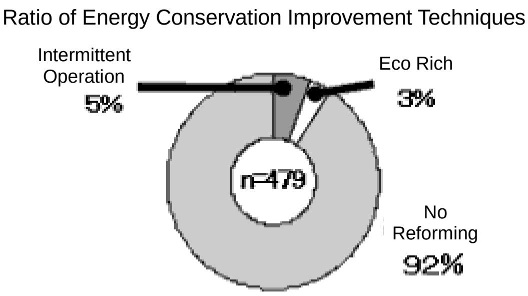


Fig. 5 Ratio of Energy Conservation Improvement Techniques

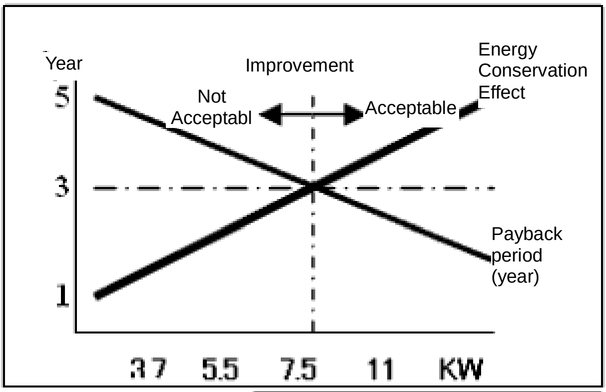


Fig. 6 Payback period (year)

The reasons that the inverter is not used are as follows, 1) The net load is less and the energy conservation effect is small, 2) it takes time to do the improvement modification, and 3) the investment recovery rate of small pumps is not profitable. However, there is possibility to install in large quantities if we can develop a low cost and easy modification technology by using the existing technologies.

3. Progress to Activities

(1) Approach of Activities and Implementation Structure

We made a test machine which ensures reliable evaluation and tests and created an environment in which we could pursue full energy conservation efficiency and conduct durability tests in order to introduce the improvement to the mass production equipment. Activity steps and role assignment are as follows. The Environment Technology Section took charge of 1) outline study to 4) durability test and the Energy Session took charge of 5) introduction to the mass production equipment to 7) expanded deployment.

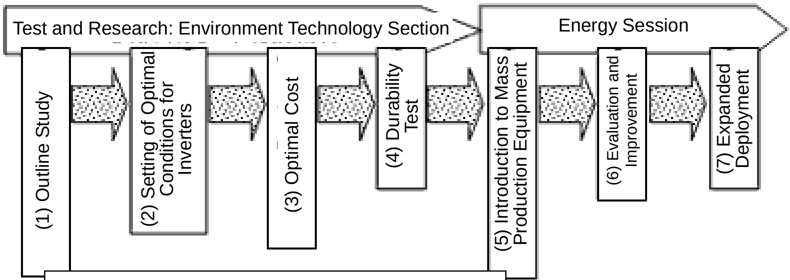


Fig. 7 Activity Step and Role Assignment

(2) Target Settings

Based on the three major indices, “easy modification which everybody can do”, “low cost within normal expenditure” and “secure effects independent of people who do the modification”, we developed our original hydraulic pump inverter control system.

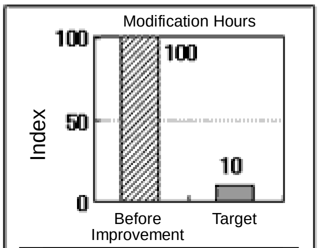


Fig. 8 Target of Modification Hours

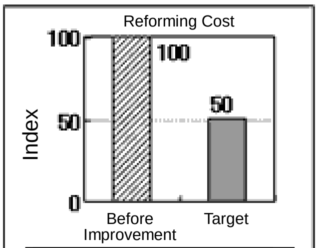


Fig. 9 Target of Reforming Cost

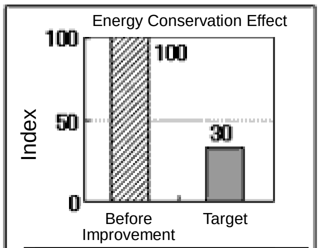


Fig. 10 Target of Energy Conservation

(3) Problem Points and their Investigation

Of the inverter control methods for hydraulic pumps: 1) The multiple step control method using control signals needs to design the sequence reforming for each piece of the equipment, which takes a very long time including test operation and study of drawings, so the mass deployment of this method is difficult. (Fig. 11)

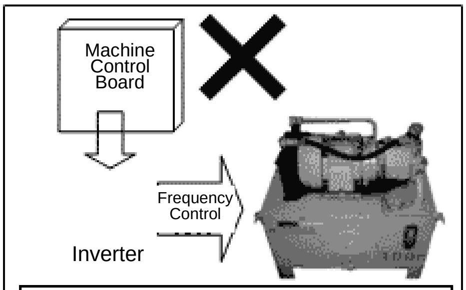


Fig. 11 Multiple Step Control Method using Control Signals

2) In case of the non-step control method using pressure sensors, it is likely to affect the cycle time and the sensor alone exceeds the budget. (Fig. 12)

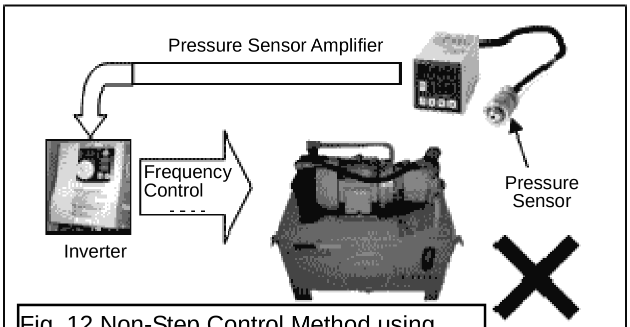


Fig. 12 Non-Step Control Method using Pressure SW

3) The 2 step control method using pressure SW can solve the disadvantages of the foregoing 2 methods and its cabling is easy. So we decided to cut the cost and improve the efficiency with this method. (Fig. 13)

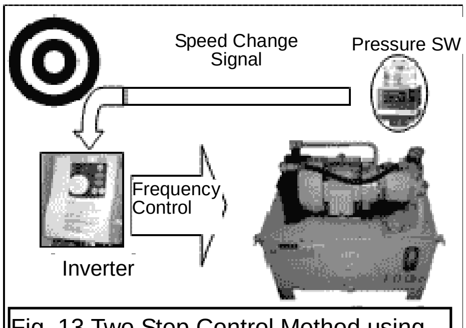


Fig. 13 Two Step Control Method using Pressure SW

4. Details of Measures

(1) Study of Easy Modification Method

Modification Method	Cost	Easiness of Modification	Evaluation	Evaluation
Put in Machine Control Board	○	×	Individual study is necessary, so mass deployment is difficult.	×
Making of Dedicated Box	△	○	Mass deployment is possible because of independent of machine side.	◎

Fig. 14 Evaluation of Inverter Installation Methods

There are 2 methods for installing the inverter, i.e. the method of putting it in the machine's control board and the method of making a dedicated board. In case of the method of making a dedicated box, its modification is costly but it is easy to do, so we adopted this method. It can be deployed in large numbers in a short period of time by installing the inverter in the pump side and making it one unit as a part of the pump.

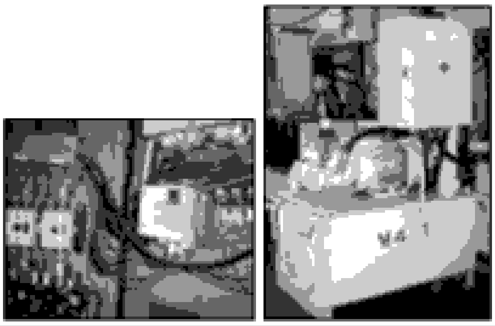


Fig. 15 Installed in Control Board (Left), Dedicated Box (Right)

(2) Study of Secure Effect Method

To solve the problems associated with conventional method, i.e. "the effect changes depending on the designer" and "the net effect is poor", we set and standardize the parameters which contribute to the energy conservation.

1) To determine the lower limit frequency at the time of standby operation

Considering the cooling efficiency of the motor and the stability of the pump, the lower limit was made to be 20HZ (58% energy conservation rate).

2) To determine the setting values of the parameters which influences the standby electricity (torque boost and base voltage).

By making the torque boost 3% and the base voltage 190V, the electricity consumption was reduced by 17%.

3) To determine the upper limit frequency at the time of the automatic operation (1 cycle operation)

When there is load, the upper limit frequency is lowered from 60 HZ to 50 HZ.

4) To control the cycle time delay by optimizing the acceleration time.

If the acceleration time is that of the standard setting (5 seconds) as is, it affects the cycle time. If it is too short, over current trouble may happen and the electricity consumption increases.

◆ The limit of the acceleration time is 0.5 seconds and this must be the reference value when horizontally deploying the improvement. However, if there is extra time in the cycle time and the acceleration time is set at 1 second to 2 seconds, the electricity consumption is reduced by 3% to 5%.

Fig. 16 Parameter Values Determined

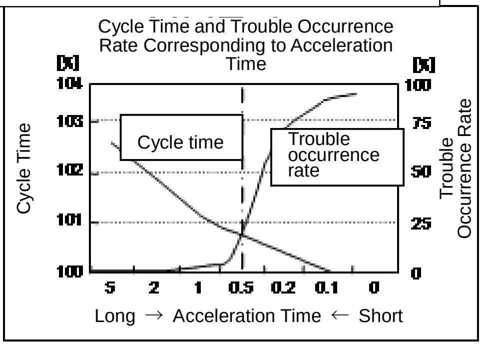


Fig. 17 Parameter Values Determined

KWh	Standard Setting of Electricity Consumption	Torque boost 3%, Base Voltage 190V	Net Load Rate	Energy Conservation Rate
Without Inverter	0.80KWh		36%	0
50 HZ Fixed	0.72KWh		33%	10%
30HZ←→50HZ	0.65KWh	0.63KWh	29%	21%
20HZ←→50HZ	0.6KWh	0.58KWh	26%	28%

Determined by torque boost 3%, base voltage 190V and frequency 20 to 50 HZ.

<Confirmation of Effect using Test Machine>

The test machine is operated in relatively more versatile ways and, in general, its standby time is longer than this and the energy conservation effect is improved by 5% to 10%.

Especially with the equipment whose automatic start is activated manually, secure effect can be expected.

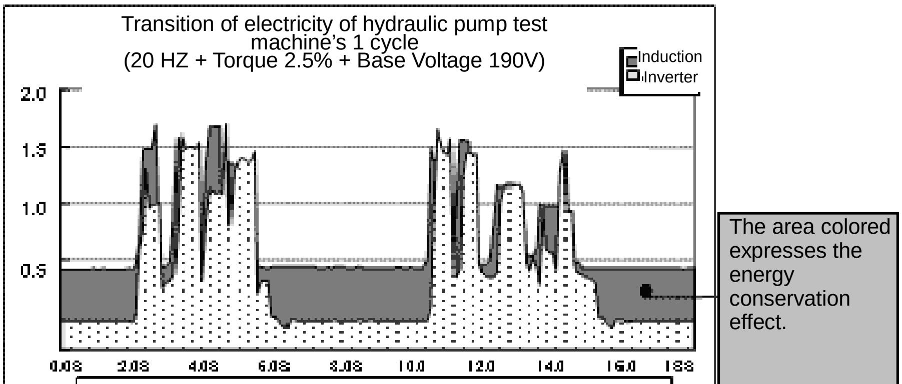


Fig. 18 Transition of Electricity Consumption at the Time of Automatic Operation

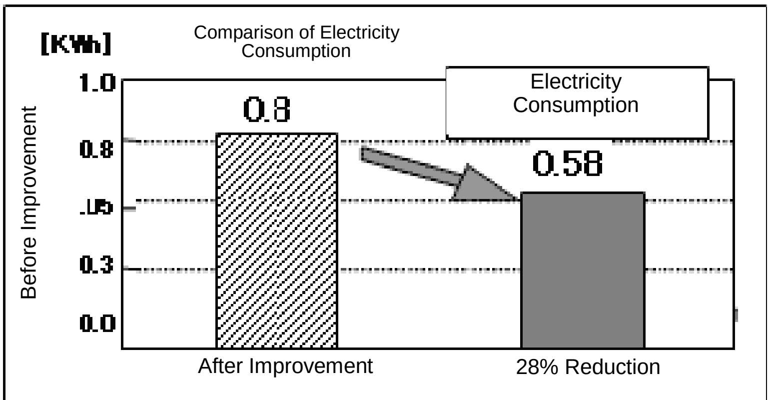


Fig. 19 Comparison of Electricity Consumption Before and After Improvement

(3) Lowering the Cost

To deploy the improvement to the mass production lines, we decided to set the specification and cut the cost. The preconditions for deciding the specifications of the inverter board and for setting the production cost are as follows, i.e. 1) low cost small inverters, 2) DC reactor for dealing with high frequency, 3) timer for smoothing the signals and 4) installation of trouble indication lamps. The payback period for the total investment amount were made to be 3 years or less.

So we introduce the hydraulic pumps with capacity between 7.5 kW and 2.2 kW and whose pay back time is within 3 years in average.

We adopted type of TDV-4F of Taihei Boeki Co., Ltd. for the pressure SW and type of FR-E520 of Mitsubishi Electric Corp. for the inverter.

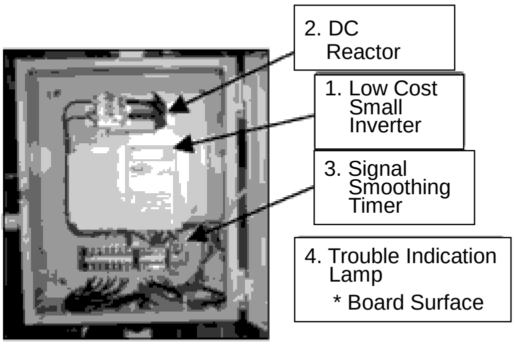


Fig. 20 Completed Inverter Board

Motor Rating	Electricity Consumption (kWh)		Yearly Electricity Saving	Yearly Monetary Amount of Effect	Upper Limit of Improvement Cost	Final Amount	Pay back perido
	Before Improvement	After Improvement					
1.5KW	0.60	0.39	1,109KWh	13 M yen	40 M yen	72 M yen	5.4 Years
2.2KW	0.88	0.57	1,626 KWh	20 M yen	59 M yen	77 M yen	3.9 Years
3.7KW	1.48	0.96	2,735 KWh	33 M yen	98 M yen	87 M yen	2.7 Years
5.5KW	2.20	1.43	4,066 KWh	49 M yen	146 M yen	126 M yen	2.6 Years
7.5KW	3.00	1.95	5,544 KWh	67 M yen	200 M yen	141 M yen	2.1 Years
						Average	2.8 Years

Calculation Base
- Electricity Consumption: Before Improvement (Rating x 40%), After Improvement (Electricity Before Improvement x 65%)
- Yearly Electricity Saving: (Electricity Consumption Before Improvement – Electricity After Improvement) x Yearly Operating Hours 5.28H
- Yearly Operating Hours: 22H/Day x 20 Days/Month x 12 Months
- Monetary Amount of Effect: Yearly Electricity Saving x Electricity Unit Price 12 Yen/kWh
- Upper Limit of Improvement Cost: Monetary Amount of Effect x 3 Years

M yen :Thousand yen

Fig. 21 Motor Capacity and Scope of Inverter Deployment

(4) Specific Modification Method

The modification is completed with 4 steps. Step 1) Remove the existing pressure gauge, install the T-type connector to be branched and install a pressure gage. Step 2) Install the inverter board on or near the top of the hydraulic tank. Step 3) Connect the cable between the motor and the pressure SW (remove the cable to the motor and connect it to the inverter, and connect a new cable from the inverter to the motor). Step 4) After turning on the power supply and setting the parameters, start the motor, adjust the pressure SW and finish the test operation. With these steps, the modification is completed. Especially the test operation is much easier than previous ways. It finishes in about 5 minutes.

Check of the automatic operation is basically not necessary, but, just for the confirmation, check the operation in the morning of the day when the system is used.

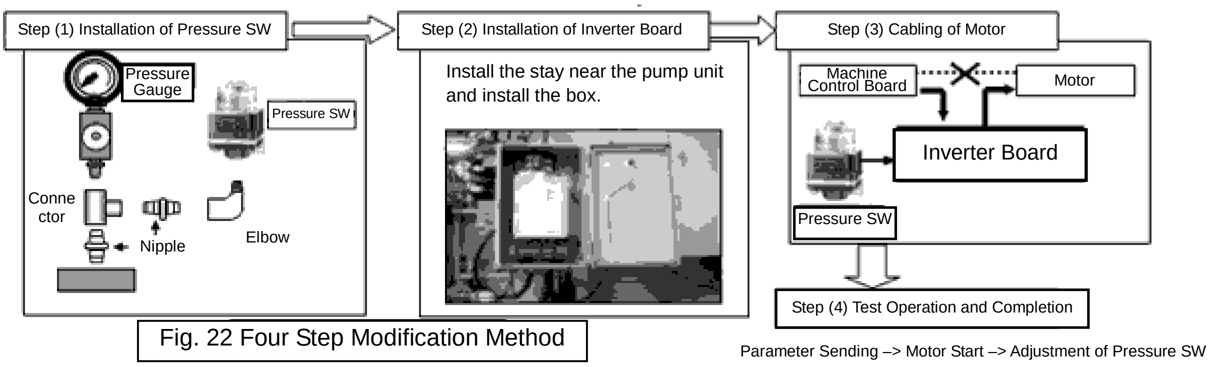


Fig. 22 Four Step Modification Method

(5) Equipment not Covered by Pressure Interlocked Inverter Control

1) Transfer machine — The load fluctuates frequently, so the effect is low. If the load fluctuates less, it is possible.

2) Double pump — The pressure SW must be installed at the discharge sides of each pump, so it raises the cost. And the load fluctuates frequently, so the effect is not expected.

3) Vane Pump — The standby electricity is little, so the effect is not expected.

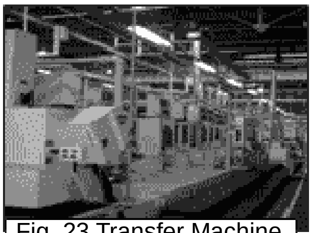


Fig. 23 Transfer Machine

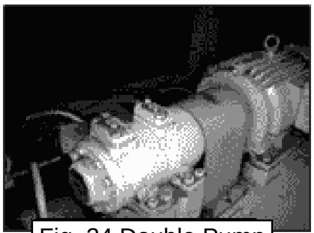


Fig. 24 Double Pump


Fig. 25 Vane Pump

(6) Deployment to Mass Production Lines (First Step)

Using the 3 consecutive holidays in April, 2003, we modified 41 delivery processing lines. As a result of sampling measurement, it was found that there was reduction effect of more than 30% in average, ranging from 26% up to 45%.

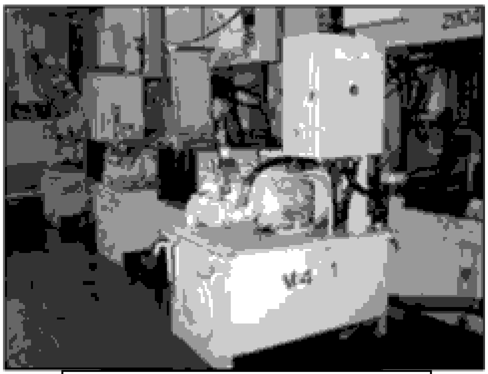


Fig. 26 Completed Modification

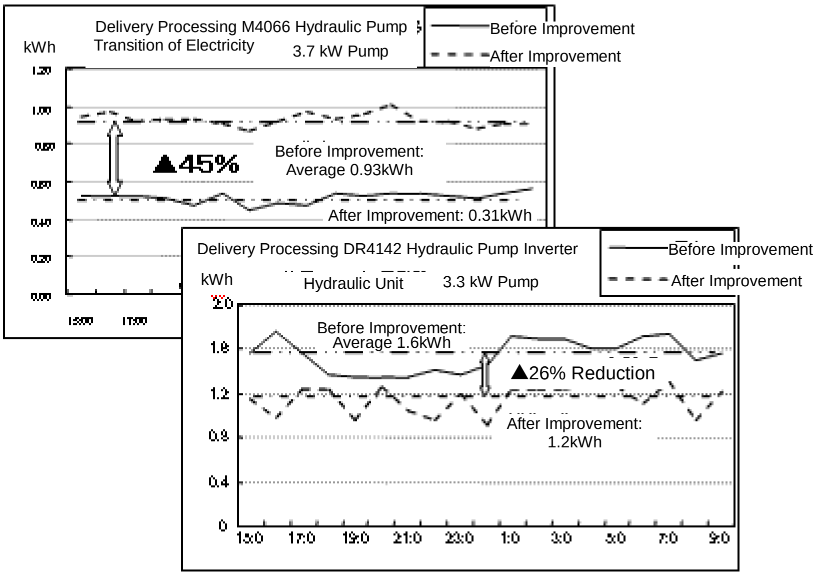


Fig. 27 Energy Conservation Effect

In the summer of 4 months after the modification, the inverter overheated. Although no trouble was caused by it, in case the heat staying causes trouble in the future, we decided to take measures to prevent such trouble and to make the expanded deployment in the future smooth.

(7) Measures for Heat Staying in Inverter Board

The current inverter board is equipped with a louver for discharging heat and the inverter itself is equipped with a cooling fan. But the heat just circulates in the board. The service life of the condenser built in the inverter is greatly influenced by the temperature.

◆ Examination of temperature and inverter service life.

The life of the aluminum electrolysis condenser used in the inverter is estimated by “the Law of Aleneum (10℃ twice rule)", i.e. if the temperature increases by 10℃, the service life is halved and if the temperature decreases by 10℃, the service life becomes twice.

◆ Details of measures

We cut the back of the BOX and exposed the inverter's heat discharge fin outside. By doing this, the heat is efficiently cooled down without being stored in the BOX.

However, as the cooling fan is easily dirty, it must be cleaned in the routine maintenance.

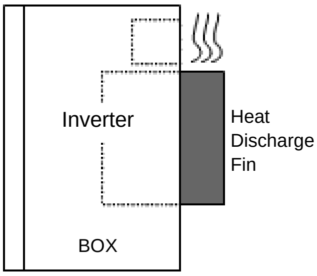


Fig. 28 Measures for Heat Staying

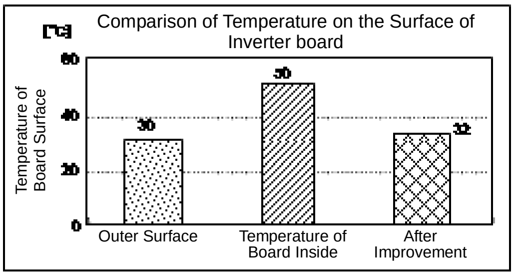


Fig. 29 Effect of Measures for Heat

(8) Deployment to Mass Production Lines (Second Step: Introduction of Heat Measure Model)

17units of impregnated pressure resistant lines were modified in 2 days of July, 2003 and, as a result of the sampling check, the reduction effect of 30% to 36% was confirmed. Since then, the modification was implemented on Saturday and Sunday of every week, and 160 units were modified by the end of December, 2003.

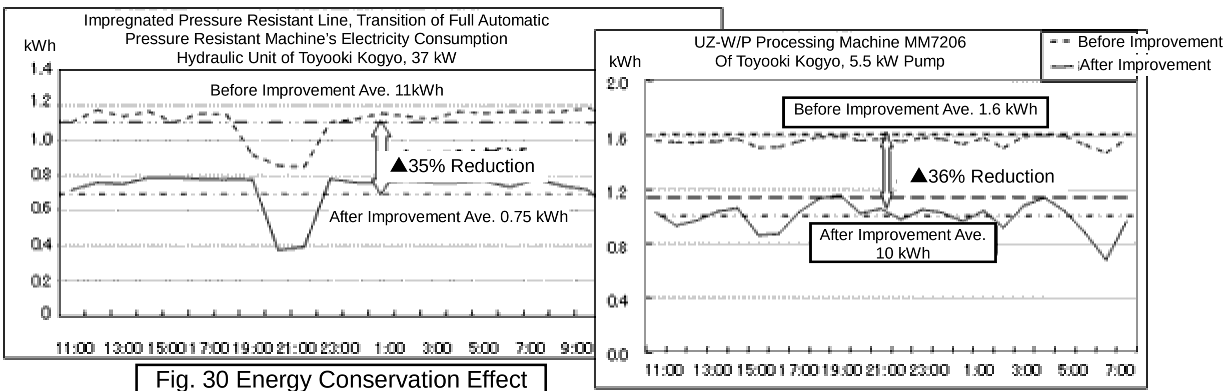


Fig. 30 Energy Conservation Effect

(9) Aiming at 100% Application to Existing Pumps

When implementing the modification, abnormal load happened in some cases and forced us to give up the modification. Judging from the phenomena, it seemed that the torque was in shortage against the load. When studying the measure, we noticed there was a flux vector control mode in the inverter's functions.

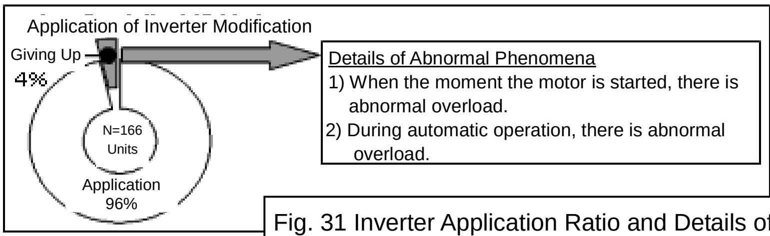


Fig. 31 Inverter Application Ratio and Details of Trouble

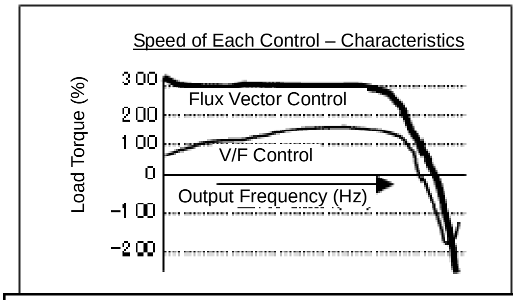


Fig. 32 Torque Characteristics of Each Control

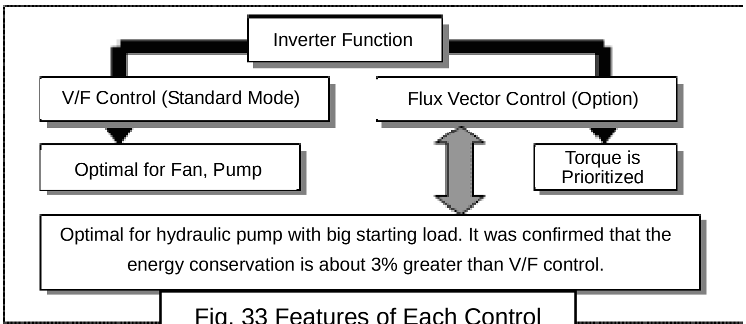


Fig. 33 Features of Each Control

Although the flux vector control is strong in the low speed torque and can follow rapid change of the load, its energy conservation efficiency seemed to be low compared with the standard V/F control. However, when tested with the test machine, it was found that above fear did not apply to the hydraulic pump and its electricity consumption was about 3% less than the V/F mode. When we applied the flux vector mode to the 6 units which had not passed the previous examination, they started to operate without any problem. So we horizontally deployed this control to all of the units. Meanwhile, when the flux vector control mode is activated, the parameters “torque boost” and “base voltage” are disabled, so they are excluded from the setting items.

By the way, the vector control or equivalent function is available in the inverters of main makers.

Control	Standby Electricity	Ratio	Automatic Operation (1 Minute Measurement)	Ratio	Final Parameters Setting Items (Of Mitsubishi Electric: #420)
No Modification	0.66KWh	100%	0.986KWh	100%	Pr.2 (Lower Limit Frequency) = 20 Hz, Pr.4 (High-Speed) = 50 Hz Pr.7 (Acceleration Time) = 0.5s, Pr.79 (Operation Mode) = 0 Pr.80 (Motor Capacity) = When input, the flux vector control is selected (Note 1).
V/F	0.298KWh	45%	0.762KWh	77%	
Vector	0.274KWh	42%	0.737KWh	75%	
(Note 1) As regards the setting method of the flux vector control, see the operation manual. (Note 2) Pr.75 Reset Selection, Pr.77 Parameter Writing Prohibited, etc. are changed as necessary.					

Fig. 34 Final Parameter Setting Table

5. Effects achieved after Implementing Measures

	2.2KW	3.7 KW	5.5 KW	7.5 KW	Total
No. of Units Modified	59 Units	95 Units	38 Units	1 Unit	193 Units
Electricity Saving Amount	106MWh	286MWh	170MWh	6MWh	567MWh
Monetary Amount of Electricity Saving	1,267 Thousand Yen	3,430 Thousand Yen	2039 Thousand Yen	73 Thousand Yen	6,809 Thousand Yen
Improvement Cost	5,157 Thousand Yen	9,177 Thousand Yen	5,122 Thousand Yen	149 Thousand Yen	19,605 Thousand Yen
Recovery Years	4.1 Years	2.7 Years	2.5 Years	2.0 Years	2.9 Years

Fig. 35 No. of Units Modified and Effect

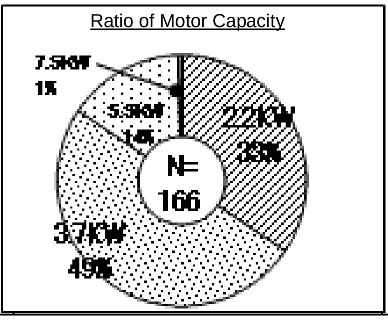


Fig. 36 Ratio of Motor Capacity Deployed

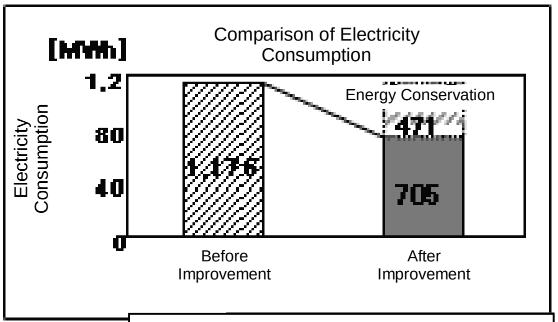


Fig. 37 Energy Conservation Effect

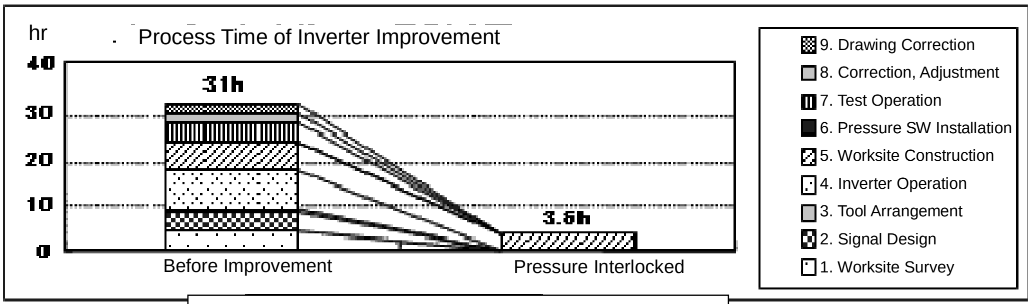


Fig. 39 Comparison of Improvement Processes

6. Summary

The important things about this improvement were that we integrated the systems into one unit as a part of the hydraulic unit without touching anything in the control board. By doing so, we could “securely create the effects at low cost” and deploy the improvement in bulk to the existing equipment in a short period, which was our original intention. Our improvement is receiving a lot of inquiries in and out of the company, developing high evaluation.

7. Future Plans

Pursuing further cost saving and energy conservation, we will continue the improvement and deploy the 1.5kW motor which was not covered by the improvement of this time.