2004 Grand Prize of Minister of Economy, Trade and Industry

Reduction of factory air by using blowers for air blow

DENSO CORPORATION, Toyohashi Plant
Cooler and Heater Production 3rd Division, Production Planning Group

◎ **Key words**：**Rationalization of conversion from electricity to motive power and heat facilities using motor and electric heating, etc.**

◎ Outline of Theme

In the factories which make various parts, air blow is used at many places to remove water and foreign substances from the parts, to carry the parts, etc. The air blow normally uses air compressed by a compressor (we call it factory air, and it is compressed to 0.5MPa).

We recently developed technique that enables us to do the air blow using blower's low pressure air (0.05MPa or less), still obtaining the same blowing force as before. We could achieve a great effect by applying this technique to already-existing air blow systems, from simple systems to more complicated systems.

◎ Implementation of the said Example

- Planning period: January, 2000 – March, 2000 (Total 3 months)
- Implementation period: April, 2000 – October, 2003 (Total 43 months)
- Confirmation period: October, 2000 – March, 2004 (Total 42 months)

◎ Outline of the Business Establishment (Cooler and Heater Production 3rd Division)

- Production items: Parts of car air conditioners (clutches, blowers, compressors, etc.), CO_2 water heaters
- Employees: 1,100 people (As of August 1, 2004)
- Yearly energy consumption (2003, actual)

Electricity (bought)	64,890 MWh/year
LPG	711 ton/year
Bunker A	3,363 kL/year

◎ Outline of Process

The production processes for clutches as our main product are shown in Fig. 1 below. As shown in this figure, this site is a factory making various parts by pressing, cutting, washing, etc.

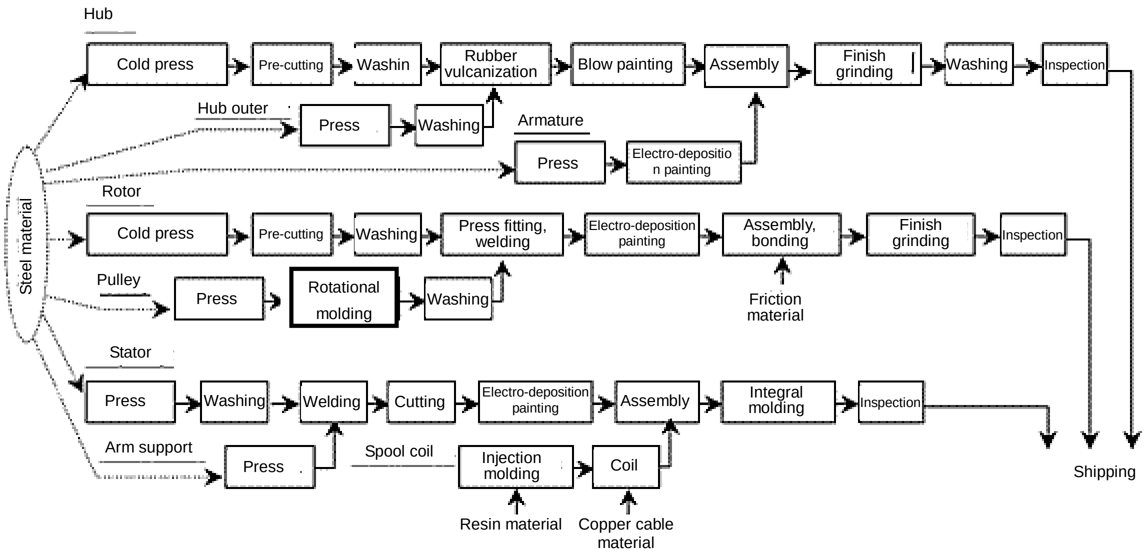


Fig.1 Clutch production processes

1. Reasons for Theme Selection

Denso made a plan called “Eco vision 2005” in 2000. Following this plan, the company as a whole tried to achieve CO_2 emission reduction and energy conservation not only for the products but also for the production facilities. In the production facilities, the company gave specific targets to each division to promote the CO_2 emission reduction as shown in Fig.2.

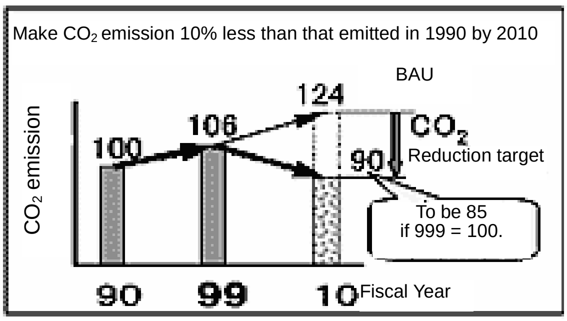
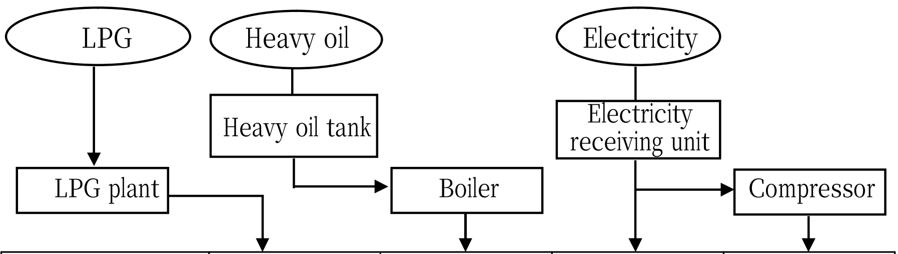


Fig.2 CO_2 reduction target of Denso

At the parts processing lines of this division, air blow is used at many places to remove water, foreign materials from the parts, etc. This air blow uses air compressed by a large compressor (compressed to 0.5MPa in this division). However, when we estimate the unit price of various kinds of energy using in the company, we can know that the unit price of the factory air is as high as 6 times than that of the electricity as shown in Fig.3 and we know that the cost of the air blow using the factory air is so high.

If we could lower the pressure for the factory air, it seemed certain that there was great energy conservation. So we tried to calculate the air pressure which could obtain the same wind speed as that we could feel on a vehicle running at high-speed, for example the bullet express train (80m/sec), thenwe found out that the air pressure was as low as 0.005MPa. Based on this study, we thought that we might be able to lower the pressure of the air blow to reduce the cost, and we started to study the way to use blowers for various air blows.



	LPG	Steam	Electricity	Factory air
Energy unit price (Electricity = 100)	244/kg	18/kg	100/kWh	$15Nm^3$
CO_2 emission	0.82kg-c/kg	0.06kg-c/kg	0.104kg-c/kwh	$0.013kg\text{-}c/Nm^3$
Unit price per energy quantity	0.8yen/MJ	1.4yen/MJ	5yen/MJ	30yen/MJ

The air cost is as expensive as 6 times of the electricity cost.

Fig.3 Energy unit price of our company

2. Understanding and Analysis of Current Situation

(1) Understanding of Current Situation

Fig. 4 shows how energy is used in this division. As it shows, the factory air accounts for 20% of the total energy consumption (CO_2 emission). If we look into the usage of the factory air, we can know that the air blow accounts for 53%, i.e. more than half the total. If we further look into the usage of the air blow, we can categorize it as Fig. 5 below. As it shows, blowing off by the air, such as removal of water and foreign substances, and carriage and alignment of parts, accounts for more than 90%.

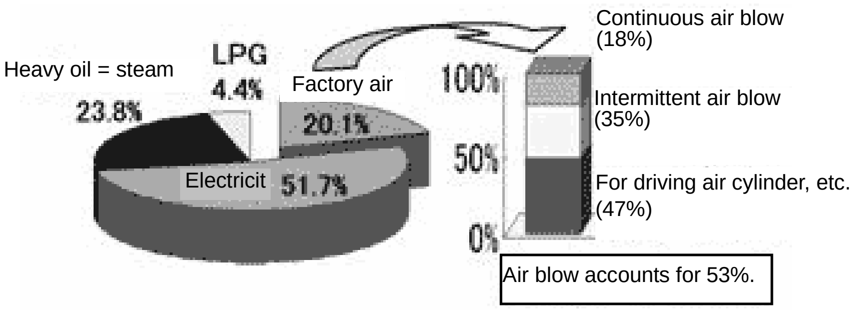


Fig. 4 State of energy use (CO_2 emission) of this division - 1999 –

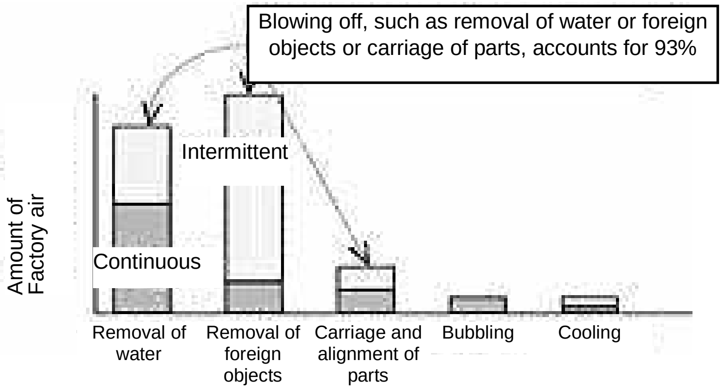


Fig.5 Usage of air blow

(2) Analysis of Current State

Fig. 6 shows one of the typical uses of the air blow. As it shows, the factory air supplied with 0.5MPa is depressurized to 0.2MPa at the vicinity of the nozzle and blown because the pipe diameter is small.

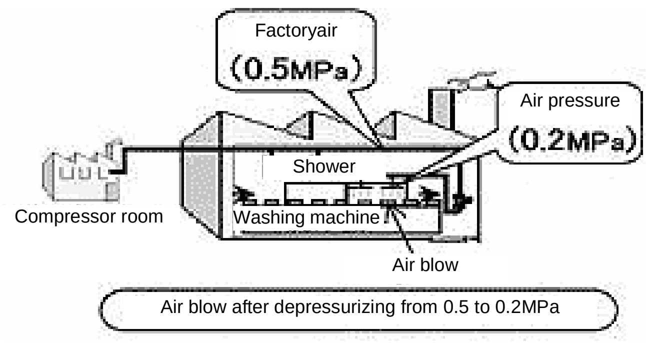


Fig.6 Current state of washing machine air blow (example)

Considering the fact that the state of the factory air changes, we calculated the work amount of the air and obtained the result as shown in Fig.7. As it shows, the valid work of the air blow is only approx. 40%, that is valid work is 3.01kw against 7.61kw of power, meaning that there is a great deal of loss due to the decrease of the air pressure.

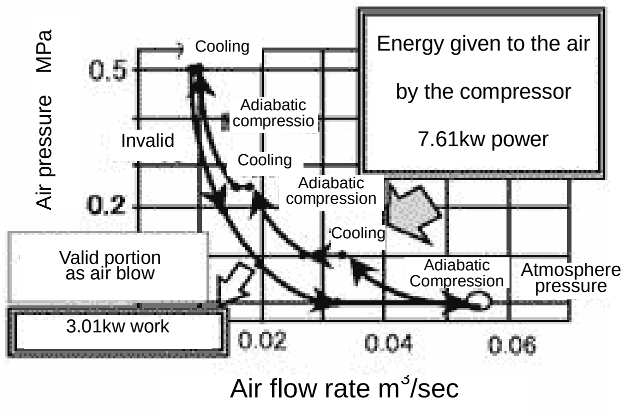


Fig.7 State change of factory air (P-V diagram)

Besides, if we theoretically study the state of the air at the nozzle outlet, we can obtain the result as shown in Fig. 8. As it shows, the air blow speed between 0.2MPa and the critical pressure of air pressure is constant at the sound speed, then it slows down, and hits the object.

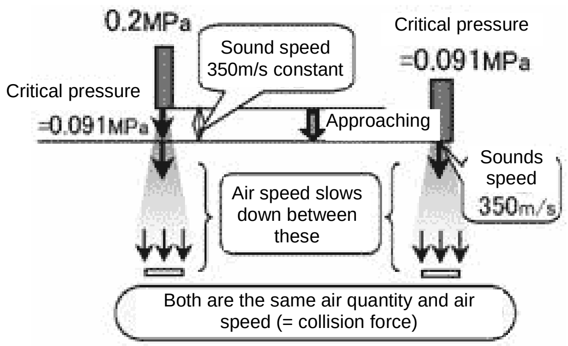


Fig.8 State of air near nozzle section

Meanwhile, if this is done under the critical pressure (=0.091 MPa), the air is blown at the sound speed, then it slows down the same as above and hits the object. Therefore, if the air volume is same and the nozzle position comes nearer to the object as shown in the figure above, the state becomes exactly the same in both cases, resulting in the same strength of the air blow. The distance that the nozzle comes nearer to the object is the distance that the pressure comes down from 0.2MPa to the critical pressure in the atmosphere, and it is supposed to be very small. In other words, if the air is blown by a blower which can generate the critical pressure, the same air blow can be obtained with same air volume, although the nozzle position must be slightly moved nearer to the object, and a great deal of energy conservation can be achieved because its electricity consumption is estimated to be 1/6 of the cost of the factory air.

Based on this study, it can be shown that the energy efficiency of the air blow using the factory air (above the critical pressure) is very poor.

3. Progress of Activities

(1) Approach of Activities and Implementation Structure

We thought that, to change already-existing state in which we depended on the factory air, it was necessary to change the mind of operators and engineers working in our factory. So we decided to focus our activities on the following 2 points. We also decided that the blower should be used for the already-existing facilities and should replace the air blow the use of which was blowing off of things.

◆ Aim of activities

1] To make it known that the blower can be used instead of the factory air by examining all of the air blow.

2] To make it known that the factory air is expensive by fully visualizing the result of the activities which are implemented to the maximum scope allowed by the investment budget.

◆ Future challenges

As shown in Fig. 9 below, the following 2 steps were repeated to improve the activities based on the experience and achievement, as if we were spiraling up.

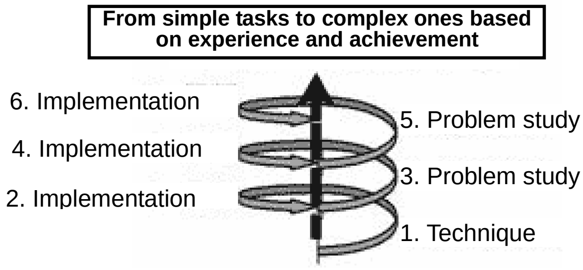


Fig.9 Implementation of activities, spiraling up image

1] Development of technique that determines the conditions for air blowing using blowers and study of various problems associated with the implementation of the technique.

2] Application to the existing facilities.

◆ Implementation structure

To implement the activities quickly in a cross-functional way, we decided to work with a few selected people. So we chose one person each from the divisions of production technology, facility design, facility making and facility maintenance to organize a dedicated group (4 people) and worked under the initiative of this group.

(2) Extraction of Problems and Setting of Targets

◆ Target for the reduction of factory air

Considering the result of the activities and the company's investment criteria (investment should be recovered within 3 years), we set up the target aiming to reduce the use of the factory air by 30% or more in a short period of time, i.e. from year 2000 up to 2003. To be more specific, we set up the target aiming to do without the continuous air blow and to cut 1/3 or more of the intermittent air blow. As regards the intermittent air blow which was difficult to recover the investment because its air blowing time was short, we decided to use the blower for multiple facilities.

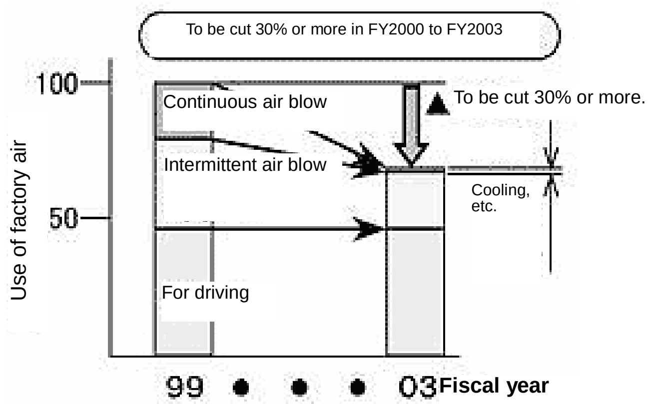


Fig.10 Specifics for achieving the target

◆ Technical problems and implementation schedule

There were following 2 problems that had to be studied to achieve the target, so we worked on them with a planned schedule.

1] Development of technique that determines the air blow conditions that realize the air blow pressure equivalent to that of the current system under low pressure (blower).

2] Schedule for developing the blower system that can cope with various air blowing types (continuous/intermittent/altogether blow).

Implementation schedule

Matters to be implemented	FY2000	FY2001	FY2002	FY2003
Development of technique that determines the air blow conditions of the blower	Development			
Development and application of blower system for continuous blow		Application		
Development and application of blower system for intermittent blow				
Development and application of altogether blower system for air blow in complex facilities				

4. Details of Measures

(1) Development of Technique that Determines the Conditions of Air Blow with the Blower (Low Pressure)

To develop the technique, we at first examined the discharge pressure of blowers commercially available in the market to determine the target value for the low pressure air, and obtained the result as shown in Fig. 11. There were water cooling roots type blower that could generate the air pressure close to the critical pressure but we had to give them up because of the cost. So we looked for other blowers. The aim of the development was to establish the technique that could make air blow equivalent to the air blow using the factory air in the existing facilities, using air pressure of 0.05MPa or less which was lower than the critical air pressure.

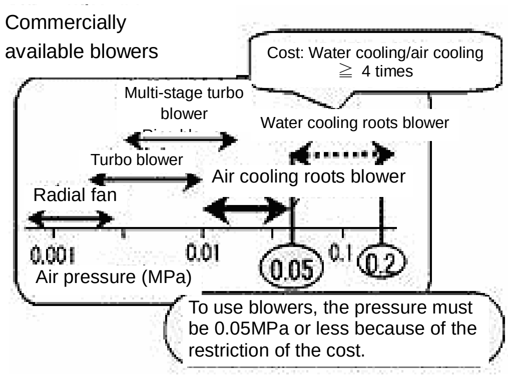


Fig.11 Research of commercially available blowers

The basic idea was to have the same air blow speed as the current air blow which hit the object by increasing the air volume and preventing the speed from being slowed down. In other words, we wanted to make up the reduction of air pressure with air volume. We started the development of technique based on this idea.

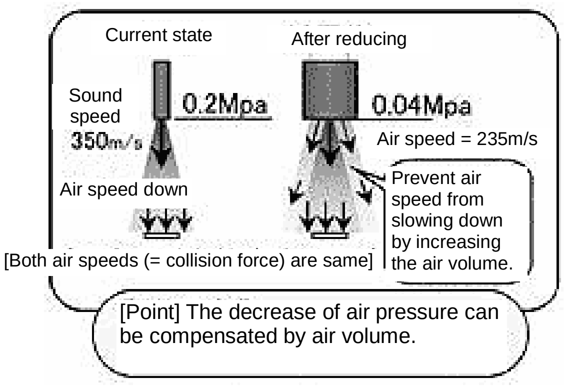


Fig.12 Concept of depressurizing

Since we were studying the air blow for the existing facilities, we picked up the air pressure and the air volume as the conditions of the air blow presuming that other conditions such as nozzle's position, distance and posture were the same as the current facilities. Then, we conducted experiments as shown in Fig.13 to determine the blower's air blow conditions that would make the same collision force as the factory air.

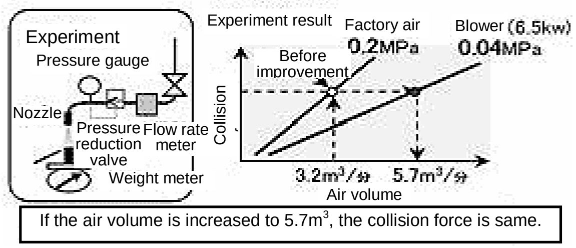


Fig.13 Experiment for determining air volume that makes same collision force.

We verified the result with a real machine as shown in Fig. 14. We were able to make the air blow the strength of which was the same as the factory air and make the energy cost 1/5 (investment recovery 1.2 years).

At the same time, we could prove that "the efficiency of the factory air was very poor, and we could create a big effect by changing it to the blower".

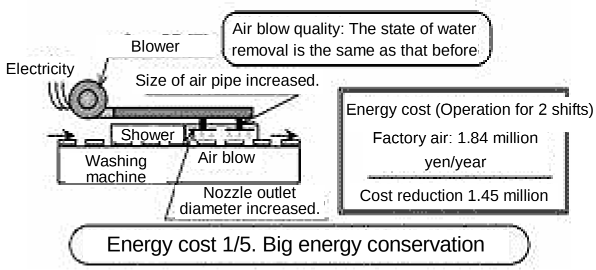


Fig.14 Washing machine air blow after improvement

(2) Development and Application of Blower System for Continuous Blow

We decided to apply the blower to the continuous blow which used a lot of factory air and which could be improved only with the technique already developed.

To apply the technique, we conducted the foregoing experiment under various conditions as shown in Fig. 15 and obtained an approximation from the experiment data in order to develop a program that "can calculate the air blow conditions of the blower only by inputting the air blow conditions of the existing facilities without conducting individual experiments". Since it was known that there was limitation to the depressurization, we determined the limitation from the theoretical formula of the force that was applied to an object in fluid and from the experiment data.

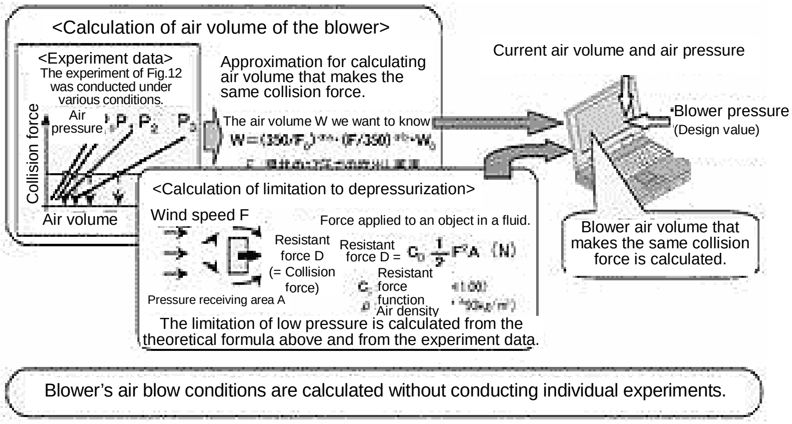


Fig.15 Blower's condition calculation program

As other tools necessary for the application, we developed automatic calculation of the pressure loss to support the design of piping and we also developed the substitute nozzles. Furthermore, we standardized the roots blower as shown in Fig.16 which were expected to be used a lot as an air supply source. To adjust the air blow strength, we decided to do it by adjusting the number of revolution with an inverter.

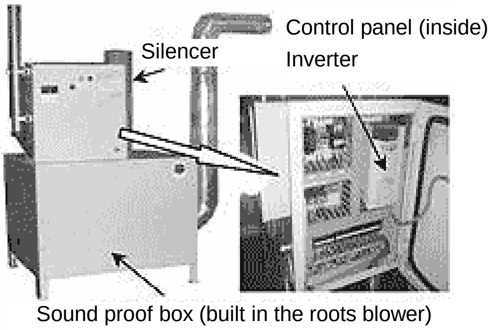


Fig.16 Standardization of roots blower

The application to the existing facilities is described later in paragraph 5 entitled "effect after implementation". In short, we worked on the action for 39 units in total and achieved big energy cost saving as much as 60.2 million yen/year (investment recovery in 1.5 years).
As regards the air blow quality, operators evaluated that "it is similar to or even better than before" or "the water removal by roots blower is better than before because it uses hot air (MAX 80℃)". So we were convinced of the effect of the blower.

(3) Development and Application of Blower System for Intermittent Blow

Next, we tried to use the blower for the intermittent air blow as shown in Fig. 17.

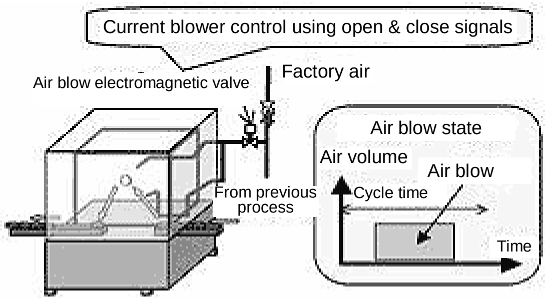


Fig.17 Example of intermittent air blow

Since we wanted to apply the technique quickly to the existing facilities, we tried to apply the blower using the air blow's intermittent signals as is without changing the existing electric control circuit (change of timing, time, etc.).

In that case, there were two problems as follows.

1] High temperature when using the roots blower (to prevent damage to the blower that might be caused by rapid temperature raise when it is stopped)

2] Pursuit of blower's high-speed following ability (how to start the blower quickly)

To cope with the high temperature, we decided to use the Hi-Lo operation of the inverter in order to cool the blower inside with a bit of cold air of very low pressure by operating the blower with Lo when stopping air blow. As regards the high-speed following ability, we decided to deal with it with Pr setting of the inverter. So we conducted various experiments to determine the best inverter Pr (for example, in case of the roots blower, Lo operation frequency: 15Hz, acceleration time: 0.3 seconds, etc.) and to standardize it for application. Meanwhile, we confirmed that, in case of the roots blower, the wasteful electricity consumption at the time of Lo operation was 1/10 or less of that at the time of 60Hz operation.

As described later in paragraph 5 entitled "effect after implementation", when applying this system to the existing facilities, we could work on only 45 units due to the restriction of the investment criteria, but we could achieve a great deal of energy cost saving as much as 36.7 million yen/year (investment recovery in 2.3 years).

(4) Development and Application of Total Blower System for Multiple Facilities

Next, in order to achieve the target of "30% reduction of factory air", we decided to work on the total blower system for multiple facilities aiming to apply the system to the intermittent air blow the investment effect of which was low.

An example of the intermittent air blow the investment effect of which is low is shown in Fig. 18 below. In this case, it was impossible to make the investment because the use of the factory air was low. So we decided to put some of these facilities together and supply the factory air to them by one blower.

In this case, there were technical problems as follows.

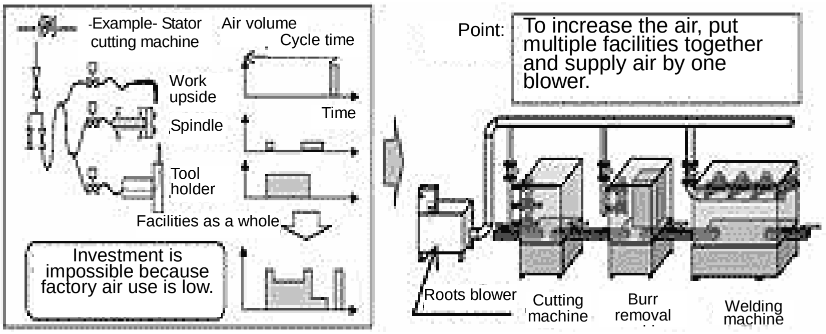


Fig.18 Example of air blow the investment effect of which is low and the use of blower for multiple facilities

1) Action for the complicated and big fluctuation of the air volume including no flow

As a general way to cope with the fluctuation of the air volume, there is accumulative tank method, but, after estimating the tank capacity, we found that it was impossible to install one because the tank was likely to become huge due to the low pressure.

So we decided to cope with the fluctuation of the air volume with the pressure PID control presuming that we use the roots blower the air pressure of which is high. Meanwhile, we thought that we should use the ON-OFF control to cope with zero air volume, because if we cope with the zero air volume with the PID control, there would be abnormally high temperature since it keeps revolving with “the number of sliding revolution” as shown in Fig. 19.

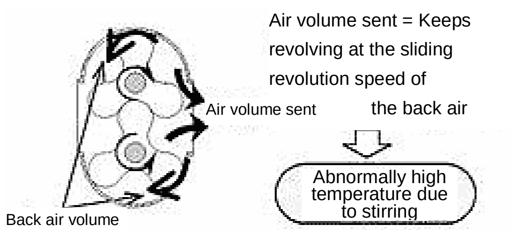


Fig.19 If air volume is made zero by PID control

So we came up with a new control system mixing the pressure PID control and the ON-OFF control (named as pressure & ON-OFF control) as shown in Fig. 20.

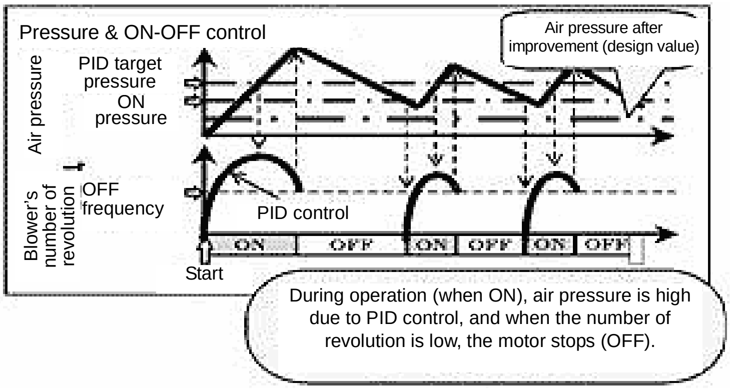


Fig.20 New control system: Pressure & ON-OFF control

Based on this pressure & ON-OFF control and the knowledge that "even if the air pressure is too high, there is no problem", and presuming that the air pressure after improvement is set below the lower limit of the fluctuation of the air pressure, we conducted tests under various conditions to study the best inverter Pr and to minimize the tank size. As a result, it turned out that the maximum discharge air volume x 1.5 seconds was enough for the tank capacity and the air pressure after improvement (design value) should be 0.03MPa or less when PID target pressure = 0.05MPa. Then, we made the inverter Pr at that time the best Pr and standardized it. Also, to cope with the extreme operation of the roots blower, we directly connected the motor and made the cooling fan independent.

Fig. 21 shows an example of this system's application and the change of its air pressure and frequency.

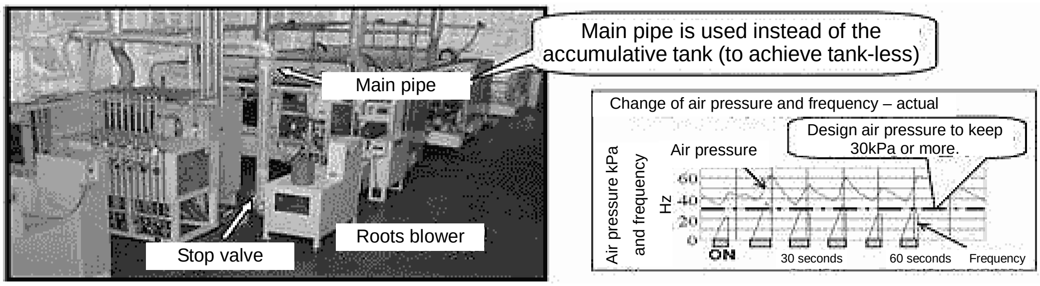


Fig.21 Example of application of blower for the total control of multiple facilities and fluctuation of air pressure and frequency

As described later in paragraph 5 entitled "effect after implementation", we applied this system to 80 units10 cases in total and achieved big energy cost saving as much as 21.9 million yen/year (investment recovery in 3.2 years).

5. Effect achieved after Implementation Measures

◆ Achievement by these activities

Implementation of these activities and CO_2 emission reduction by reducing electricity consumption for the factory air are shown in Fig. 22.

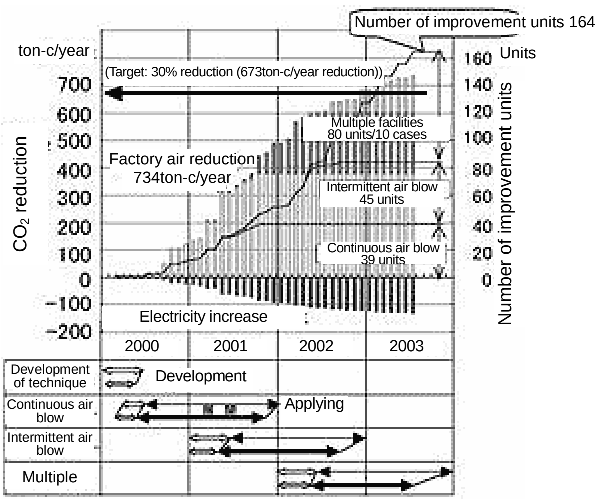


Fig.22 Implementation of these activities and CO_2 emission reduction of factory air/electricity

These activities are summarized as the table below

		Continuous air blow	Intermittent air blow	Multiple facilities	Total
CO_2 reduction t-c/year		306.6	187.7	110.8	605.3 t-c/year
	Factory air	379.2	223.2	131.1	733.7
	Electricity	▲ 72.6	▲ 35.5	▲ 20.3	▲ 128.4
Number of units improved Units		39	45	80/10 cases	164 units
Energy conservation amount Million yen/year		60.2	36.7	21.9	118.8 million yen/year
Investment recovery years Years		1.5	2.3	3.2	Average 2.1 years

We completed 5 months earlier than schedule (October, 2003) and improved 164 units in total. As regards CO_2 emission reduction, although CO_2 of electricity origin increased by 128 ton-c/year, CO_2 of factory air origin decreased by 734 ton-c/year, leading to the reduction of 605 ton-c/year as a result.

As regards the energy cost, as much as 118.8 million yen (investment recovery in average: 2.1 years) was successfully reduced.

◆ CO_2 emission reduction of this division

CO_2 emission of this division since 1999 is shown in Fig. 23, indicating that the emission has been steadily reduced,while the production has increased. Especially, the usage of factory air was reduced to 58% of 1999.

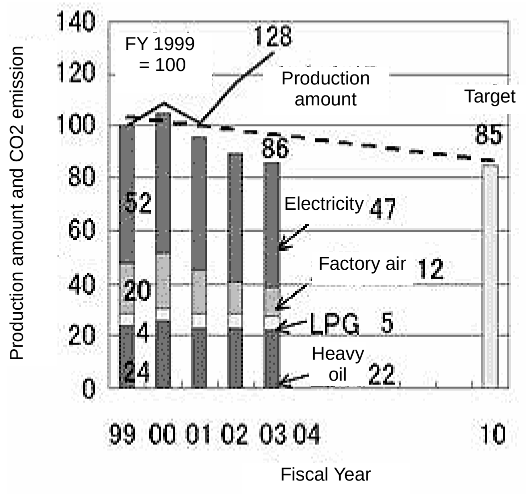


Fig.23 CO_2 emission of this division

Fig. 24 shows CO_2 emission of this factory air and compares it with the achievement of these activities. With these activities, we were able to reduce 33% of the factory, exceeding"30% reduction of the usage of factory air" as target.

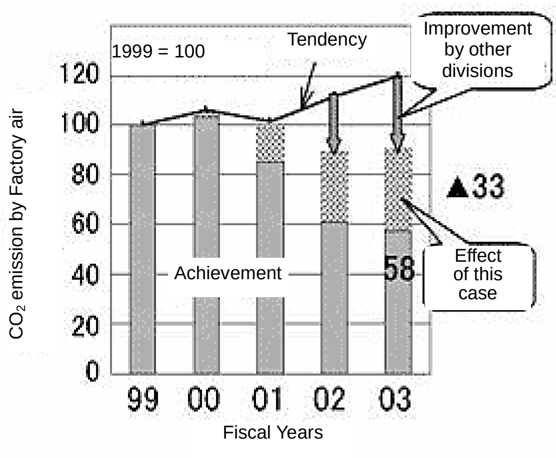


Fig.24 State of CO_2 emission by factory air

It is known that the reduction has also been achieved by measures other than these activities since 2002. They are the improvements of the factory air by the action such as prevention of air leakage by operators, use of motors for air driving equipment such as air pumps by engineers. From this, we think that "change of mind of operators and engineers" as our goal has been achieved.

6. Summary

From theoretical study, it was found that the efficiency of air blow using factory air (with pressure above critical pressure) was very poor, although it had been considered to be common sense.

To break this common sense, we dealt with the following problems trying to “change the mind of operators and engineers”.

1] To use the blower for all air blows conducted in the existing facilities.

2] Quick and full application of the improvement as far as the investment budget permits.

So we started the improvement from (1) development of technique ⇒ (2) continuous air blow ⇒ (3) intermittent air blow ⇒ (4) multiple facilities, as if we spiraled up based on our experience and achievement.

To implement improvements, we promoted the use of blower for the air blow, while standardizing various factors including calculation of new blower’s air blow conditions from the existing air blow conditions. As a result, we could achieve 33% reduction of the usage of factory air, exceeding the target (30% reduction).

Besides, as we aimed at the existing facilities, we could greatly contribute to the CO_2 emission reduction of this division and change the mind of operators and engineers so that they admitted that “the factory air is expensive and wasteful”, leading to further reduction of the usage of factory air.

7. Future Plans

We will spread and implement the technologies we made in our activities not only in the entire company but also out of the company such as for affiliated companies.

Besides, we will improve those technologies in a way that they can be used for new facilities and, by doing so, we will create production facilities which are environmentally friendly.