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ENERGY SAVING IN ROAD, TUNNEL AND ALLIED EQUIPMENT ETC.

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I. FOREWORD

Viewed from the standpoint of the present energy problem, etc., the vehicle society is topics of study, but viewed from the point that the automobile is indispensable in our present economical system and daily livlihood, whereas railways and airplanes are "lines from station to station" as a means of mass transport, the automobile is an effective means of indivudual transportation that is "door to door".

Regardless of this, Japan lags behind America and Europe in the pavement factor of roads, including high speed expressways (*Fig. 1*). Therefore, the new 7 years economic plan emphasizes road extension and its arrangement for the fullfilment of social capital. These plans widen the development to mountain roads and increases the proportion of tunnels.

The tunnels of such highways include various facilities for safety and environmental purposes. The possibility of energy saving electric facilities associated with lighting, tunnel ventilation, road heating, etc. is discussed.

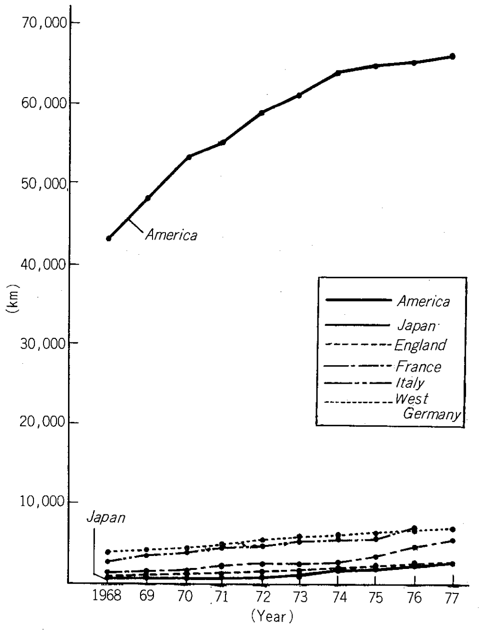


Fig. 1 Highway extension trend of main 6 countries in the world

Since the existing functions for safety and the environment must not be sacrificed for energy saving, these are specifically considered as points which demand discretion. For example, dust collection systems associated with tunnel ventilation are authorized by committees including members from government and the public and their popularization will quicken in the future.

II. SERIES LIGHTING SYSTEM

At sections of roads and tunnels that require lighting, the ordinary method of distributing power to lamps has been designed by calculating the allowable current carrying capacity of each power line and the voltage drop at the last lamp.

On the other hand, in the series lighting system, the primary side of the insulation transformer corresponding to each lamp is connected in series with cable of the same size as shown in *Fig. 2* and the lighting conditions required by the lamps should be produced at the secondary side of the insulation transformer by supplying a fixed current from a constant current source. That is, whereas the ordinary system supplies power to parallel connected lamp loads by means of "voltage", the series lighting system supplies power by means of "current". Therefore, beside solving the difference of lighting conditions of each lamps with distance from the power source, this system permits uniform light adjustment and dimming by controlling the transmitted current and can be said to be an energy saving system that meets the demands of the age.

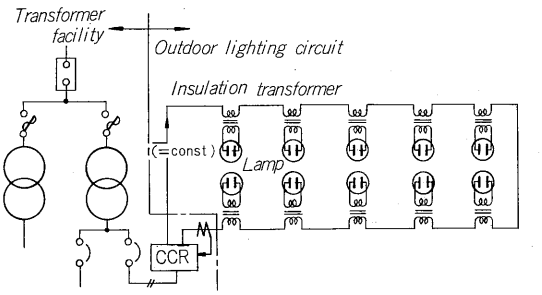


Fig. 2 Diagram of series lighting system

Such a series lighting system is not the first of its kind. The highway lighting in North America and other large countries and the airport runway landing lights stipulated by International Regulations based on the series lighting system have the following features:

(1) Since the size of the wiring cable can be equal and small, cable costs for long distances and wide areas is low.
(2) For the same reason, wiring design and wiring work are easy.
(3) The lighting conditions can be entirely equalized in any lamps including near zone or for zone from power source.
(4) Even though the power source voltage varies somewhat, the lamps are used under fixed conditions and lamp life is long.
(5) The lamps can be simultaneously turned on and off without using control lines.
(6) Even though lamps of different specifications are used, mixed lighting is possible by using the appropriate insulation transformers.
(7) Energy saving by dimming is possible and the variations in illumination are small because uniform dimming is possible.
(8) Expansion is possible without changing the size of the existing cable.

For example, if the cable cost of the ordinary system and the cable cost of the series lighting system are compared, whereas the former is proportional to the cube of the number of lamps (n), the latter can be seen to be proportional to the n at a uniform thickness (*Fig. 3*) and the if the number of lamps exceeds a certain value, the advantages of the series lighting system appear. Even when the initial facilities costs are considered, the energy saving effect by running is a further merit.

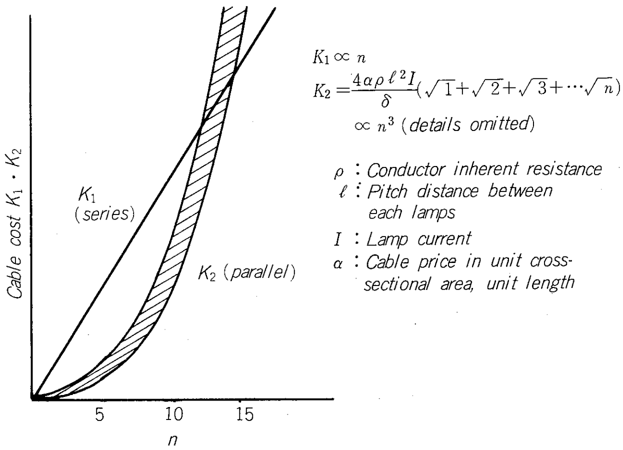


Fig. 3 Cost of wiring cable

Fig. 4 Lighting view of Hg-lamps by series lighting system

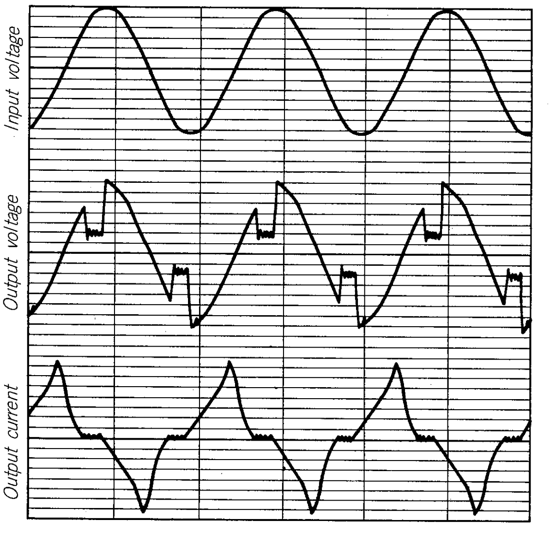


Fig. 5 Waveforms of input voltage, output voltage and output current output current

Table 1 Cost comparison between new system and ordinary system

	Equipment	Work	Remarks
(1) Items for which series lighting is advantageous	Cable, manholes	Wiring, end processing	When the number of lamps exceeds 12 ~ 13, series lighting is advantageous. Series lighting cables may use plugs and receptacle at their ends.
(2) Items for which ordinary lighting is advantageous	Choke device, switchboards, conduit	Installation of choke device	
(3) Items common to both systems	Lamps, poles, fixtures	Boring, conduit laying, refilling, pole erection, lamps and fixtures installation.	The choke device is the insulation transformer type in series lighting. The series lighting type distribution panel is the thyristor type.

Fig. 4 is an example of this system consisting of 31 mercury lamps (final installation will have 74 lamps) on the grounds of some university. The thyristor constant current regulator (CCR) of the power supply performs 100%, 80%, and 60% current adjustment according to time and plays a role in energy saving (*Fig. 5*). However, in this system, the transmission voltage may be high depending upon the number of lamps and special approval of electrical engineering standards must be obtained. However, revision of these standards will become a question with popularization of this system.

III. TUNNEL DUST COLLECTION SYSTEM

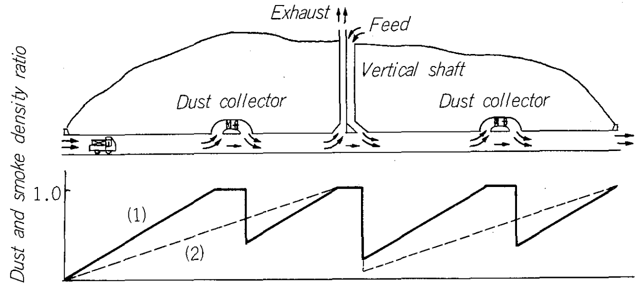
To prevent troubles (mainly poor visibility and the generation of toxic gases such as CO gas) due to the exhaust gas of the automobiles running through road tunnels, the air inside the tunnel is diluted and dispersed by taking in a large amount of fresh outside air. However, this requires large blowers.

There are longitudinal flow, semi-horizontal flow, and horizontal flow methods of performing this forced ventilation. However, if a wind cavity is provided outside of the road space or the tunnel is long, the vertical shaft or angular shaft are necessary and construction costs increase rapidly.

In a tunnel dust collecting system, the electrostatic dust collectors are installed at suitable places inside the tunnel and the smoke in the exhaust gas from cars is removed to improve the visibility inside the tunnel. Whereas ordinary ventilation is a dilution and disperison system with generation of smoke as a precondition, the ventilation system containing a dust collecting system efficiently removes the smoke in the road air by some method and dilutes the remaining smoke with the minimum amount of air and is said to permit equivalent economization of the ventilation system including the construction costs. If viewed from the standpoint of energy saving, since the ventilation power is proportional to the cube of the air amount, this system, which suppresses the air amount to the minimum, can realize a substantial energy saving.

For example, the tunnel interior density when two dust collector sets are installed in a one-way longitudinal ventilation with a vertical shaft system and for an ordinary system can be compared as shown in *Fig. 6*. The vertical axis shows the removal or dilution of the smoke at the dust collectors and vertical shaft points as the density increases according to the direction of travel of the automobiles in the normal traffic state. However, the increase gradient is associated with the feed (exhaust) air amount and becomes smaller as the dilution amount becomes larger. The dotted line in the figure is the density which must be controlled when dust collectors are not installed. In the figure, a blower air amount of approximately 1.7 times is necessary.

In other words, if the ventilation air amount at the dust collector system is assumed to be 60% of that of the ordinary system, that is, if $P \propto Q^3$ is assumed, the energy required is reduced to 20%. But the dust collector itself and sucking in of the dirty air into the dust collector and returning the clean air to the tunnel required electric energy and other points (for example, the density management is not weight density, but must be the 100 m transparency value, ventilation to dilute the CO gas, a natural ventilation effect and smoke exhaust when a fire occurs, etc.) must be



(1) *When dust collectors installed (solid line)*
(2) *Ordinary ventilation system (dotted line)*

Fig. 6 Dust density variation in tunnel with longitudinal ventilation system

Table 2 Ventilating power comparison between ordinary system and new system

Ventilation system		Horizontal flow (ordinary system)	Longitudinal flow with dust collector (new system)
Ventilating blower	(Intake)	< 0.5	> 0.09
	(Exhaust)	> 0.5	< 0.09
	Total	1.0	0.18
Dust collection system	Body	–	≒ 0
	Air blower for dust collector	–	0.09
Total		1.0	0.27

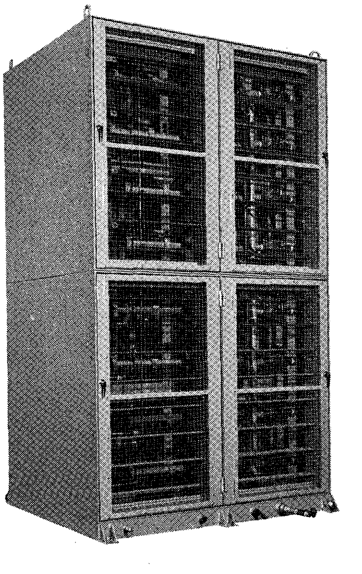


Fig. 7 Exterior view of electrostatic dust collector with air blow mechanism

Total snowfall and number of snowy days and total accumulated snow depth

	Total snowfall	Number of snowy days	Maximum accumulated snow depth
1973	592	84	78 (2.14)
1974	389	69	86 (1.19)
1975	404	60	93 (1.24)
1976	652	60	136 (2.18)
1977	364	71	88 (2.4)
1978	128	40	25 (2.2)

Number of snowy days by daily snowfall (average value from 1967 to 1978)

Daily snowfall \ Month	11	12	1	2	3	4	6 months winter season
0 ~ 10cm/d	2.8	10.2	15.5	12.8	9.9	0.8	52.0
11~20 〃	0.1	1.4	2.3	3.4	1.2		8.4
21~30 〃	0.1	0.5	1.6	0.8	0.1	0.2	3.3
31~40 〃		0.2	0.6	0.6	0.2		1.6
41~50 〃		0.1	0.4	0.1			0.6
51~60 〃			0.2	0.1			0.3
61cm/d or greater							
Total	3.0	12.4	20.6	17.8	11.4	1.0	66.2

Number of continued snow days 37.9 *days (average value from* 1967 *to* 1978*)*
Earliest: *Dec.* 22, 1973 *Latest*: *March* 13, 1977
Number of accumulated snow days 60.2 *(average value from* 1967 *to* 1978*)*

Accumulated snow chart

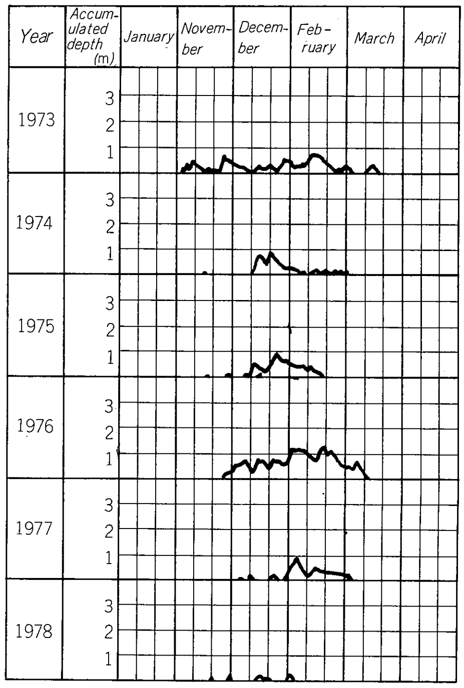


Fig. 8 Snowing conditions in recent 5 years (Toyama city)

studied individually according to the design conditions of the tunnel. *Table 2* is an example of comparison of the ordinary horizontal ventilation system and longitudinal ventilation system using dust collectors at a comparatively long tunnel, and while the dust collection facility is added at the latter, it shows that the overall facility can be made small and energy saving.

In any case, the use of tunnel dust collectors is expected to have a large affect on the tunnel ventilation system of the future and Fuji Electric will participate in the development of a consistent system through the Construction use Electric Engineering Society and will build prototypes and deliver actual machines and add sutdies on the next step. *Fig. 7* shows an exterior view example.

IV. ROAD HEATING CONTROL SYSTEM

In snowy and arctic regions, 500 W/m^2 or less heaters are buried under the road at bridges, the entrance and exit of tunnels, pedestrian bridges, and other places where freezing easily occurs and when snow removal is difficult and these heaters are controlled to keep safety conditions of road in the winter. If the heat buried area per one location is assumed to be 1,000 m^2 and the operating time of the four months of winter (December ~ March) is assumed to be several hundred hours, the electric charges reach the order of several million yen. Of course, as shown by the case of Toyama city in *Fig. 8*, the operating time differs widely with the weather conditions of the year, and for this reason, the possibility of energy saving is necessary to consider adopting the optimum control system.

Present road heating is performed manually by grasping the weather conditions and traffic volume, or automatic control is performed with the air temperature and road temperature, water component, snowfall amount, wind velocity, amount of sunlight, and traffic volume as sensor conditions. Regarding the latter, it is difficult to say that the present functions are not insufficient, but in any case it is the most simply ON-OFF control system, and since there is a time delay or setting value margin, there is no wasted power.

On the other hand, this new system has thyristors at the road heater power supply and its output is continuously variable and performs so-called PI control by receiving the sensor conditions and it is assumed that speedy output adjustment according to changes in the weather conditions will reduce wasteful power costs. As a result, on site measurement is most accurate, but producing the various conditions by computer simulation is advantageous as pattern analysis. The simulation results when heaters are

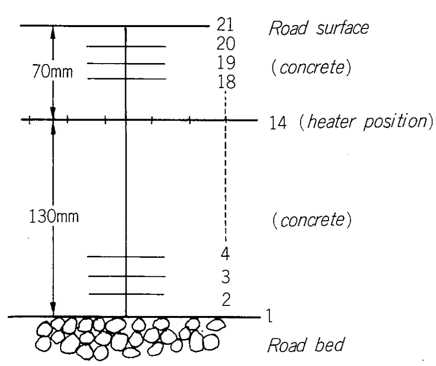


Fig. 9 Example of cross-section by concrete pavement

buried 70 mm from the surface of a 200 mm concrete paved road as shown in *Fig. 9* are given here.

Simulation was performed on the new system and ordinary system for comparison. *Table 3* and *Fig. 10* (a) and (b) are examples. That is, it is a time transition of the response of each parts and power consumption for 96 hours of repetition of snowfall strength 0.5 cm/h, 4 hours snowfall, 4 hours no snowfall. TAS-21, -14, and -2 in the figure

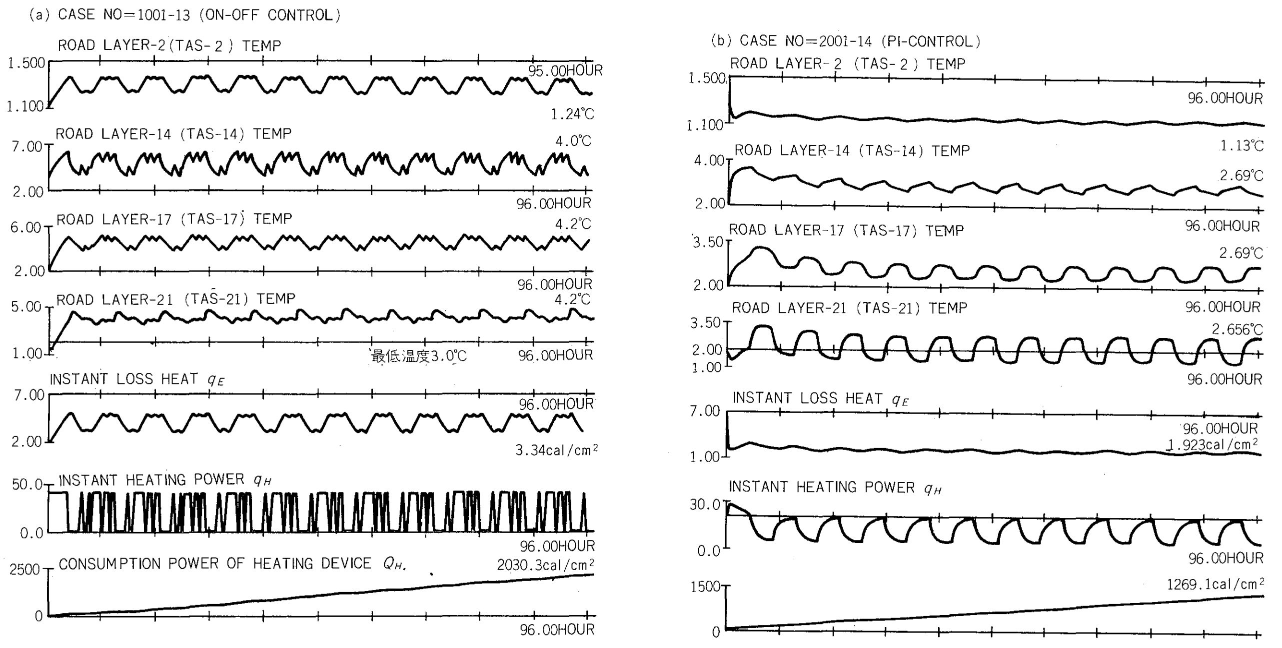
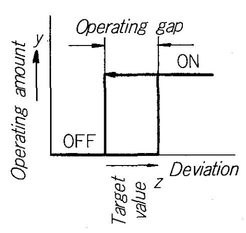
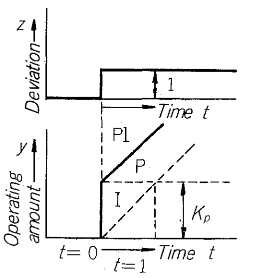
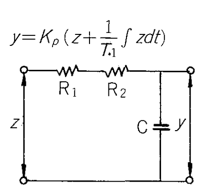
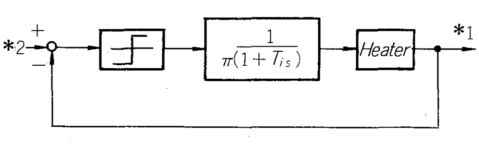
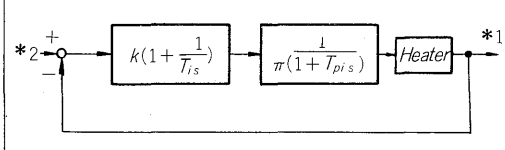


Fig. 10 Computer simulations of ON-OFF control and PI control

Table 3 Comparison of ON-OFF control and PI control

Control system	ON-OFF control (ordinary system)	PI control (thyristor power supply use)
Description of operation	One of two set values are taken according to whether the control deviation is plus or minus.	Operation proportional to the control deviation (P operation) and operation proportional to the integrated value of the control deviation (I operation) are combined.
Inditial response		 
Control system (control set temperature → road temperature)		
	*1: Maintenance of road temperature within 1 °C regardless of the amount of snowfall is made the target. *2: Control set temperature = 1 °C + α Where, $\alpha_{ON\text{-}OFF} > \alpha_{PI}$	

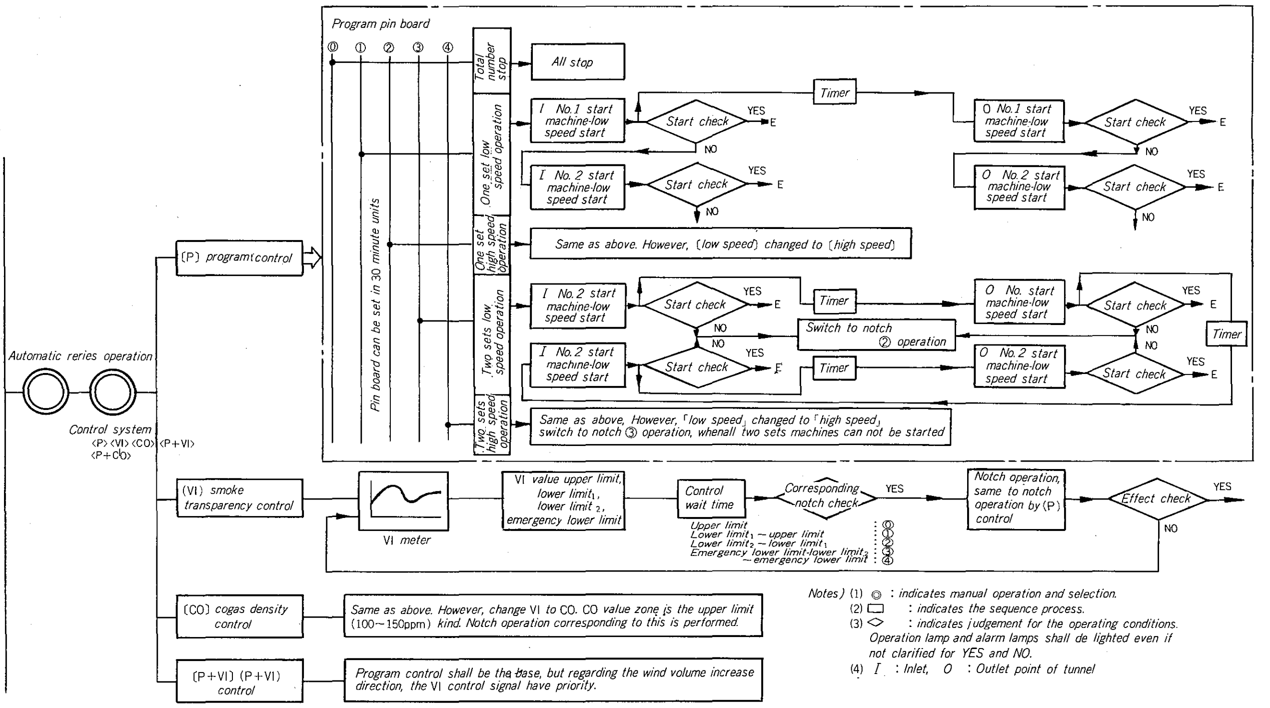


Fig. 11 Control of wind volume by running sets control and pole change control of induction motors

Table 4 Dimension comparison between some kinds of transformers

Item	Oil-filled transformer	Class H dry transformer	Moulded transformer
Floor space	1.0	0.59	0.53
Volume	1.0	0.45	0.41
Weight	1.0	0.82	0.81

Table 5 Reducing of running costs as a result of reducing power consumption

Operating conditions when 1 day is made the standard		Reduction of Fuji power moulded transformer for class H dry system	Reduction of Fuji power moulded transformer for oil-filled
24 hours 100% load	24 hours 100% load	7,884,000 yen	5,432,000 yen
	12 hours + 12 hours 80% load 50% load	3,602,000 yen	2,314,000 yen
12 hours + 12 hours excited unexcited	12 hours + 12 hours 100% load No load	3,842,000 yen	2,716,000 yen
	12 hours + 12 hours 80% load No load	2,584,000 yen	1,702,000 yen

Note) 1) When operated for 10 years length
2) Electric charge held at 20 yen/kWh.

Fig. 12 Electric indicating panel with solar cell (America)

mean the temperature of the road surface, heater surface, and No. 1 layer from the road bed and q_E, q_H, and Q_H means the amount of heat escaping at the road bed, heater calorific value and heater accumulated calorific value. As can be seen from the figure, PI control has a fast response speed and can maintain the road temperature at a temperature near the control set value and the power consumption is reduced to 62% (1,269/2,030=0.62). From the simulation results, when the controller gain is made large, the road maintenance temperature approaches the set value and the power consumption is almost unrelated to the magnitude of the gain.

Therefore, if a heater facility larger than the ordinary facility and a thyristor power supply and PI control system corresponding to the snowfall can be simultaneously expected.

V. OTHERS

1. VVVF

The ventilating air flow proportional to the length of the tunnel and the traffic volume is necessary for a highway tunnel. Ventilation motors of several hundred kW are installed at tunnels about 2 km for this purpose. Ordinarily, these ventilation facilities consists of several induction motors and is matched to the traffic volume and the air flow is adjusted by dividing the 40 ~ 100% into four steps by means of running sets control and pole change control as shown in *Fig. 11*. Making such step control VVVF (variable voltage variable frequency) by means of the optimum control, energy saving, or maintenance-free concept will naturally be studied with the progress of thyristor power supply equipment and cost reduction in the future. Since the consumption of the electric power is proportional to the cube of the air flow, if limited to the low air flow region, introduction can be said to be easy from the standpoint of cost also.

2. Molded transformer

Transformers are indispensable in stepping down the received voltage to the distributed voltage and stepping down the distributed voltage to power, lighting, and other load voltages in a power system. Because of years of improvements and static devices, transformers have been made more efficient compared with other. However, since the development of the fire-resistant molded transformer to replace the PCB nonflammable oil several years ago, its popularity has increased rapidly and Fuji Electric has manufactured a large capacity 30 kV class 7,500 kVA unit said to be the world's largest. Since this transformer incorporates new ideas in the winding construction part and resin having superior insulation characteristics is used as the coil insulation, the pitch between the coil turns could be made much smaller than that of either the oil-filled type or the ordinary Class H dry type, the coil occupancy is good and the core can be made small, and the transformer loss is lightened and other energy saving effects cannot be overlooked. For example, *Table 4* shows a comparison of the specifications of various 3-phase, 6 kV class 50 Hz 500 kVA transformers and *Table 5* shows the reduction of running costs. In addition, since the molded transformer also features a rugged construction, high moisture-resistance, low noise, etc., its use in unmanned electric rooms, tunnel ventilation electric rooms, etc. is expected to increase.

3. Solar cell

Various new energies are being developed to relieve our dependence on oil. However, since highways, tunnels and other facilities contain traffic and meteorological sensors, fire devices, telephone, signs, and other comparatively low power devices and receiving power to the installation site of these devices from the electric power company is difficult, solar and wind power, etc. small scale local processing generating systems are expected in the future. *Fig. 12* is an example of an electric indicating panel using a solar cell in America, but at present, such device are still not in general use from the standpoint of economy. However, Fuji Electric is practicalizing amorphous sollar cell and if the cost can be made several ten percent cheaper than the current cost and the charging system improved, this field is sure to become popular.

VI. CONCLUSION

Energy saving in the electric fields associated with road and tunnel facilities was discussed above. Generally, energy saving is not achieved through new technology, but often by accumulated detailed study. Moreover, since the problem of running costs, or energy saving, is also frequently accompanied by an increase in initial investment, the value judgement standards must be clarified and the effect confirmed by more concrete studies.

The contents of this theme has many branches and many things were insufficiently described here, but new energy saving aimmed at reducing our dependency on oil is a large theme for both today and the future, the authors will be happy if this article provide some reference to the related persons.