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A. Gilius, L. Brazdeikis

1. Introduction

Fresh air in heat recovery section of modern ventilating equipment is heated by air taken from ventilated spaces. Amount of heat from the air, which could be used, in most cases is insufficient and additional water or electric heaters thus are installed (Fig 1) with automatic power load adjustment to get temperature of supply air at desirable established value.

In electric heaters of low capacity, approximately up to 15 kW, the thyristor base regulators with continuous change of power load are mostly used. The heaters of larger power load usually are divided into groups and the power load is regulated by stepping regulators. The principles of phase regulation or low frequency pulse modulation are applied then for the control of alternating current thyristor power (voltage) regulators. For equipment with thermal inertia it is better to use the pulse regulators, which have less undesirable effect on the electric net in comparison with analogous phase controllers [1]. The effect of pulse regulators on the electric net and the object under control depends on pulse regulation density and pulse range [1]. It is important to select optimal values of these quantities.

Stepping regulators, while changing power load for heating by steps of certain magnitude, would unavoidably cause the commutative fluctuations of the parameter under control - supply air temperature. Therefore the number of steps and power load range at the least step should be selected carefully.

2. Purpose of the investigation

The purpose of investigation is to establish the optimal properties for thyristor pulse power load regulators of electric heaters in ventilating equipment, to evaluate the effect of pulse regulators on heater and electric net, to form the basic requirements for stepping heaters and regulators as well as for projecting the electric net when pulse regulators are used.

3. Investigation method

Low pulse regulators on alternating current (Fig 2a) and stepping regulators (Fig 2b) have been investigated. The diagrams of output voltage in pulse regulator as well as of temperature of heating elements changes are shown in Fig 3.

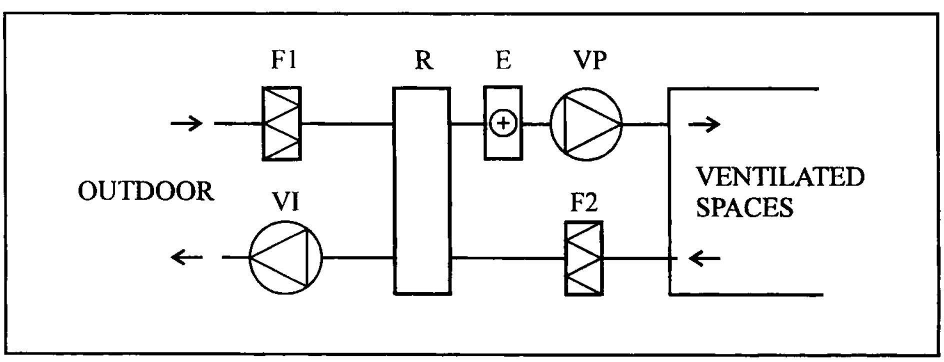

Fig 1. Simplified functional scheme of ventilating equipment: F - air filters; VP , VI - supply and extracting fans; R - rotating or plate heat recovery unit; E - heater for supply air

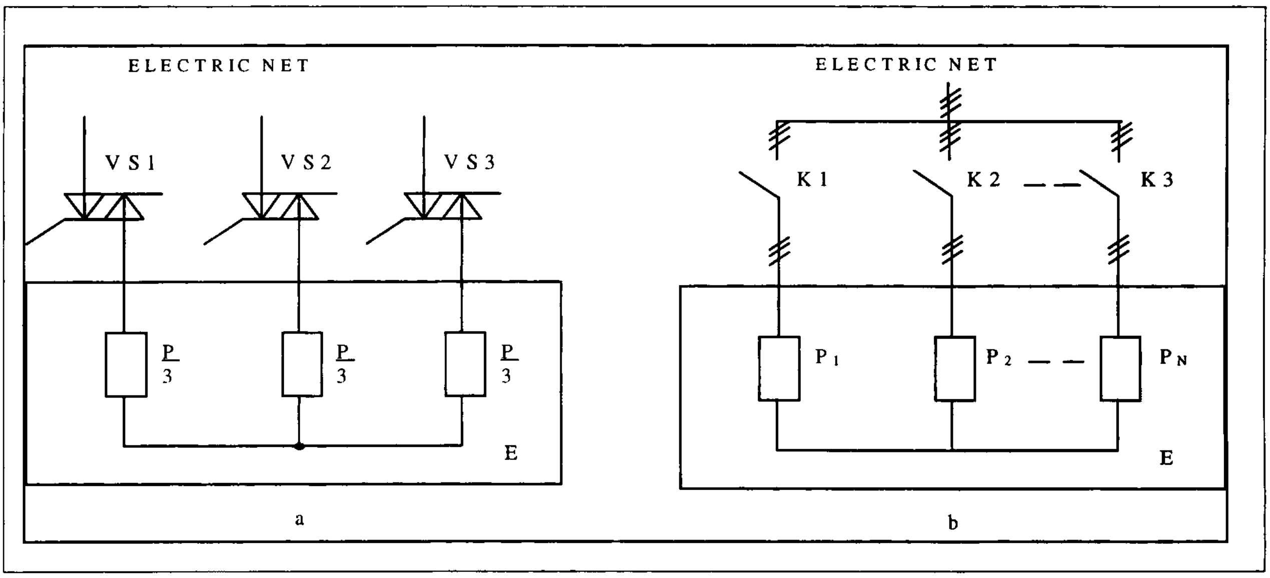

Fig 2. Functional schemes of pulse (a) and stepping (b) regulator: ***E*** - electric heater; ***P*** - power load of electric heater; P_r - power load of separate group in electric heater; ***VS*** - contactless switches (thyristors or triacks); ***K*** - switches on contacts (contactors).

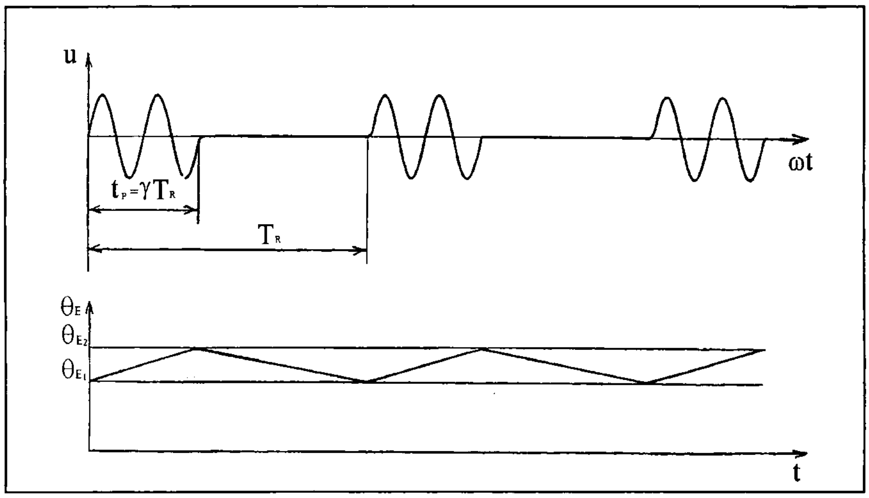

Fig 3. Diagrams of pulse regulator voltage and heating elements temperature change: ***u*** - output voltage for pulse regulator; t_p - range of permeance; T_R - regulation period; γ- pulse regulation density; Θ_E- temperature of heating elements

The basic parameters of pulse regulation are selected: regulation period T_R, duration of permeance range t_P and mode of change for pulse regulation density γ. These parameters are selected on the basis of analytic calculations, evaluating in complex the temperature fluctuations of heating elements and supply air, and the effect of regulator on the electric net as well. The calculations results are checked by measuring the temperature fluctuations of heating elements and supply air in ventilating unit ABZ-4 with electric heater of 9 kW produced by ABB.

The dependence of commutative temperature fluctuation of supply air due to the number of regulation steps and their power load is established by analytic calculations at the investigation of stepping regulators.

The specific requirements for power load regulators of ventilating equipment heaters and for projecting the maintenance electric net are formed at summarizing investigation results.

4. Investigation results

The principle of pulse modulation is applied in most cases for control of pulse regulator, which functional scheme is described in Fig 2a, when regulation period $\mathbf{T_R}$ is kept as constant parameter and mean output power load is adjusted by change of permeance range duration $\mathbf{t_P}$. By the decrease of mean power load in the regulator (at minimal permeance range), the frequency spectra of current is widened and negative effect of such regulator on the electric net increases [1]. Therefore it is better to adjust the mean power load by changing both regulation period as well as permeance range duration [2].

Mean output power load at pulse regulator is proportional to the pulse regulation density:

$$P_{mean} = \gamma \cdot P_0 = P_0 \cdot \frac{t_P}{T_R}, \qquad (1)$$

where P_{mean} - mean power load of pulse regulator; P_0 - power load at the direct connection to the electric net; t_P - permeance range duration for pulse regulation; T_R - regulation period.

The temperature fluctuation of heating elements caused by pulse regulator could be determined as indicated by [3]:

$$\Delta\Theta_E = \frac{P_E}{\sum c_i \cdot g_i} \cdot T_R \cdot \gamma \cdot (1-\gamma), \qquad (2)$$

where $\Delta\Theta_E$ - temperature fluctuation of heating element, $\Delta\Theta_E = \Theta_{E2} - \Theta_{E1}$, Fig 3; P_E - nominal power load of heating element; c_i - heat capacity coefficients for components (spiral, filling, envelope) with varying temperature; g_i - masses of components with varying temperature.

The equation presented above is formed under the assumptions that temperatures of all components mentioned above are changing uniformly and simultaneously, and the heat transfer does not depend on considered temperature fluctuations.

In reality, heat transfer in heaters depends on temperature of heating elements. The alteration of heat transfer suppresses the temperature fluctuations, thus real temperature fluctuation of heating elements would be less than calculated according to the expression (2).

The temperature fluctuations of heating elements in various ventilating equipment having been calculated, on the basis of analysis provided, it could be suggested to estimate maximum values of heating elements temperature fluctuation by the equation:

$$\Delta\Theta_{E\max} \approx T_{R\min}, \qquad (3)$$

where $\Delta\Theta_{Emax}$ - maximum temperature fluctuations of heating element, ^{0}C; T_{Rmin} - least regulation period, corresponding to the regulation density at γ**=0,5** [2], s.

Temperature fluctuations of supply air could be estimated according to the equation:

$$\Delta\Theta_P = \frac{\Delta\Theta_E \cdot \Delta\Theta_V}{\Theta_{EV}}, \qquad (4)$$

where $\Delta\Theta_P$ - temperature fluctuation of supply air; $\Delta\Theta_V$ - nominal supply air temperature increase; Θ_{EV} - nominal (largest) temperature of heating elements.

It could be perceived from equations (3) and (4) that pulse regulation period should be decreased with the aim to decrease the temperature fluctuation of supply air. Therefore, the voltage fluctuation caused by the regulator restricts the decrease of pulse regulation period, because of permissible amplitude diminution in the net when the frequency is increased [4]. The voltage fluctuation at operating of pulse regulator is calculated as follows:

$$\Delta U = \frac{P \cdot r}{U_V \sqrt{3}}, \qquad (5)$$

where ΔU - voltage fluctuation in electric heater; P - nominal power load of electric heater; U_v - nominal linear voltage of electric net; r -resistance in one phase of electric net from the heater to the supply transformator. This resistance ought to be so little that the voltage fluctuation could not exceed the fluctuation permitted by proper requirements [4].

Maximum temperature fluctuation of heating elements in electric heater of ventilating unit ABZ-4 with nominal capacity of 9 kW, controlled by pulse regulator, when the least regulation period T_{Rmin}=11 s, calculated according to the equation (2) is $\Theta_{E\max}$ =11,7°C. Evaluating that nominal temperature increase of supply air by considered heater $\Delta\Theta_V \approx$14°C and nominal temperature of heating elements $\Theta_{EV} \approx$300°C, the temperature fluctuation of supply air calculated according to the equation (4) is equal to $\Delta\Theta_P$ =0,55°C. Measured temperature fluctuation of heating elements has been observed at (4±1)°C and temperature fluctuation of supply air at (0,3±0,1)°C. The comparison of measured and calculated values could prove that maximum limit temperature fluctuation calculated according to the equations (2) - (4) will never be exceeded at normal operating condition of real ventilating equipment.

The heater power load, the amount of supply air and selected possible temperature fluctuations of supply air will define the number of steps in stepping regulator:

$$N \geq \frac{3P}{L\Delta\Theta_P} = \frac{\Delta\Theta_V}{\Delta\Theta_P}, \qquad (6)$$

where N - number of steps with equal power load in stepping regulator; P - nominal power load of electric heater; L - design supply air amount, m^3/h; $\Delta\Theta_P$ - selected possible temperature fluctuation of supply air, °C; $\Delta\Theta_V$ - nominal temperature increase for supply air, °C.

The stepping regulators are used in heaters, where the heating elements are divided into groups. Heating elements usually are grouped so that the ratio of power load by the groups would correspond to the sequence 1:2:4:8. In such case, the sufficient number of power load steps is formed at the least amount of groups:

$$N = 2^K - 1, \qquad (7)$$

where K - number of heating elements groups.

The electric heaters of 3 or 4 groups and stepping regulators of 7 or 15 steps are used in most cases. As the electric heaters in ventilating equipment increase supply air temperature by approximately 15 °C, the commutative temperature fluctuations of supply air caused by stepping regulators could be about 2 °C, when regulators of 7 steps are used, and about 1 °C, when the number of steps is equal to 15.

The combined, stepping-continuous regulation is also applied. This type of regulation is used mostly when the groups of heating elements have equal power load. In this case one of the groups is controlled by a pulse regulator, and the others are commutated by contactors. The combined regulation does not create the settled commutative temperature fluctuation of supply air, as the power load at a certain step is adjusted by pulse regulator, then the temperature and voltage fluctuation caused by pulse regulator only could be evaluated according to the presented equations.

5. Conclusions

1. Pulse regulators with change of regulation period and permeance range at the minimum regulation density of 10-15 s should be applied for adjustment of power load in ventilating equipment of low capacity (up to 15 kW).

2. At projecting electric net for maintenance of pulse regulators it is necessary to evaluate voltage fluctuation created. Voltage fluctuation usually does not exceed the permissible values if the design power load of electric net is more than twice as large as the power load controlled by pulse regulator.

3. The stepping of 7 or 15 steps regulators or combined stepping-continuous regulators should be applied for the adjustment of electric heaters of larger capacity. The regulation mode is coordinated with power load ratio of heating element groups in electric heater.

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VĖDINIMO ĮRENGINIŲ ELEKTRINIŲ ŠILDYTUVŲ GALIOS REGULIAVIMAS

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Santrauka

Šilumą taupančiuose vėdinimo įrenginiuose į patalpas pučiamą orą pašildo per šilumos rekuperatorius iš patalpų ištraukiamas oras. Dažniausiai šio pašildymo nepakanka, todėl papildomai įrengiami vandens arba elektros šildytuvai, kurių galia reguliuojama automatiškai.

Tyrimų tikslas – nustatyti vėdinimo įrenginių elektrinių šildytuvų galios tiristorinių impulsinių reguliatorių optimalius rodiklius, įvertinti impulsinio reguliatoriaus įtaką šildytuvui ir elektros tinklui, suformuluoti pagrindinius reikalavimus laiptuotiesiems šildytuvams ir laiptuotiesiems reguliatoriams projektuoti.

Vėdinimo įrenginių nedidelės galios (maždaug iki 15 kW) elektrinių šildytuvų galiai reguliuoti taikytini impulsiniai kintamo reguliavimo periodo ir kintamo laidumo intervalo reguliatoriai, kurių minimali reguliavimo periodo trukmė – 10-15 s. Tokių reguliatorių sukuriami šildymo elementų paviršiaus temperatūros svyravimai dažniausiai neviršija 10 °C, pučiamo oro temperatūros svyravimai neviršija 0,5 °C, o sukuriami elektros tinklo įtampos svyravimai neviršija leistinų, jei elektros tinklo projektinė skaičiuojamoji galia ne mažiau kaip du kartus didesnė už impulsino reguliatoriaus valdomą galią.

Didesnės galios elektriniams šildytuvams valdyti taikytini 15 arba 7 laiptų reguliatoriai arba kombinuotieji laiptuotieji tolygūs reguliatoriai.

Straipsnyje pateikiamos matematinės lygtys, pagal kurias galima apskaičiuoti impulsinių reguliatorių sukuriamus didžiausius ribinius šildymo elementų ir pučiamo oro temperatūrų svyravimus, impulsinių reguliatorių sukuriamus elektros tinklo įtampos svyravimus bei laiptuotųjų reguliatorių sukuriamus pučiamo oro komutacinius svyravimus. Aptariamam matematiniam modeliui patikrinti pateikiami temperatūrų matavimo rezultatai realiame vėdinimo įrenginyje.

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