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DEVELOPMENT OF AN IMPROVED OPTICAL-ELECTRONIC LINEAR SMOKE DETECTOR WITH DISCREET CONTROL ZONES

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Abstract: An improved design of a single-component optical linear smoke detector with discrete movement and stopping at intermediate control points using a reed-resistor array and a reversible motor is proposed. The device provides multi-point monitoring of air optical density, accelerates fire detection, and enhances system reliability while complying with regulatory requirements.

Keywords: Linear smoke detector, reed switch, reed-resistor array.

Linear fire detectors can serve as one of the fundamental components of modern fire alarm systems [1]. Their operating principle is based on detecting the occurrence and development of a fire directly along the optical beam line connecting an infrared emitting unit (emitter) and a receiving unit (receiver). A detailed analysis

of their functional and operational characteristics, as well as specific application features of this detector type, is thoroughly examined in [2].

Among the various technical implementations of such devices, so-called single-component optical linear smoke detectors have gained increasing popularity in recent years [3]. Their main structural difference lies in the fact that the emitter and receiver units are combined into a single housing. To ensure the reflection and return of the infrared beam back to the receiving optical system, a specialized reflector (retroreflector) is mounted on the opposite wall or structural partition of the room [4]. Its design allows for redirecting the optical beam with minimal attenuation coefficients and intensity losses.

According to current regulatory standards [5], when designing and installing linear smoke detectors in rooms with ceiling heights exceeding 11 meters, a two-tiered arrangement must be provided:

- the first (lower) tier is installed at a height of not less than 1.5-2 meters above the defined fire load level, but no lower than 4 meters above floor level;
- the second (upper) tier is mounted directly in the ceiling zone – at a distance of no more than 0.8 meters from the ceiling (roofing) level.

Under this configuration, the algorithm for generating the "Fire" signal by the subsystem is executed in several stages. Upon actuation of the first-tier detectors, the fire alarm system transitions to the preliminary "Attention" state. If the initial smoke occurrence is subsequently confirmed by the actuation of the second (upper) tier detectors, the system fully switches to the "Fire" alarm mode, triggering the corresponding notification and automatic fire suppression scenarios.

This two-tiered installation method for linear detectors significantly increases detection reliability and minimizes the probability of false alarms. However, its implementation leads to a substantial increase in equipment quantity, higher consumption of installation materials and cabling products, and significantly elevates the total cost of installation, commissioning, and ongoing maintenance of the system.

To optimize capital expenditure and improve the economic efficiency of fire alarm systems in spaces over 11 meters high, an improved design of a

single-component optical-electronic linear smoke detector was proposed in [6]. By utilizing a single "emitter-receiver" optical pair, this design enables sequential or dynamic monitoring of the air's optical density across two required height levels-directly above the fire load and within the upper ceiling space.

A drawback of this design is that monitoring is limited to only two levels, the distance between which can exceed 10 meters. According to various estimates [7, 8], the vertical smoke propagation speed typically ranges from 0.5 to 3-5 m/s (i.e., from 20-30 m/min under normal building conditions to over 200-300 m/min in high-temperature vertical shafts). Consequently, in a typical horizontally oriented room (where height is smaller than any other dimension), the time required for smoke to travel from the first tier of linear detectors to the second can reach up to 1-1.5 minutes. Naturally, this parameter depends on numerous factors – smoke and combustion product temperature, room geometry and height, the presence of a draft/stack effect, among others. Nevertheless, even considering a medium-complexity fire scenario during the first 10 minutes, the fire radius expands by 0.75–1 m/min.

Therefore, real-time air composition monitoring at intermediate elevations between the lower and upper bounds becomes highly relevant. To achieve this, the design of the linear detector [6] must incorporate the capability to halt at intermediate inspection points.

A "permanent magnet – reed switch" pair can serve as the positioning mechanism to stop the linear detector at designated points. A reed switch (short for "hermetically sealed contact") is an electromechanical switching device whose contacts open or close under the influence of an external magnetic field.

The permanent magnet is integrated into the movable optical block, which travels along a guide rail. Normally open (NO) reed switches with series resistors R are soldered along the entire length of the rail. As the permanent magnet approaches a given reed switch, its ferromagnetic blades become magnetized, attract each other with opposite poles, and close the electrical circuit. When the magnetic field moves away, elastic forces return the blades to their initial state, opening the circuit.

Instead of relying on only two limit switches (top – bottom), closing each individual reed switch generates a unique output voltage V_{out}. This analog value is fed directly to the analog input of the drive control microcontroller. The microcontroller instantaneously reads the voltage level to accurately determine the current position coordinate of the optical carriage on the guide rail. Upon reaching the target intermediate reed switch (detected via the corresponding V_{out}, the microcontroller issues a stop signal to the motor driver.

The general arrangement of the device is shown in Figure 1.

An additional advantage of this design compared to the model proposed in [5] is the automated tracking of detector movement and jam detection of the moving carriage. If the elapsed time between actuation of adjacent reed switches exceeds the pre-calibrated threshold, the system registers a mechanical obstruction event and halts the drive unit moving the detector along the rail.

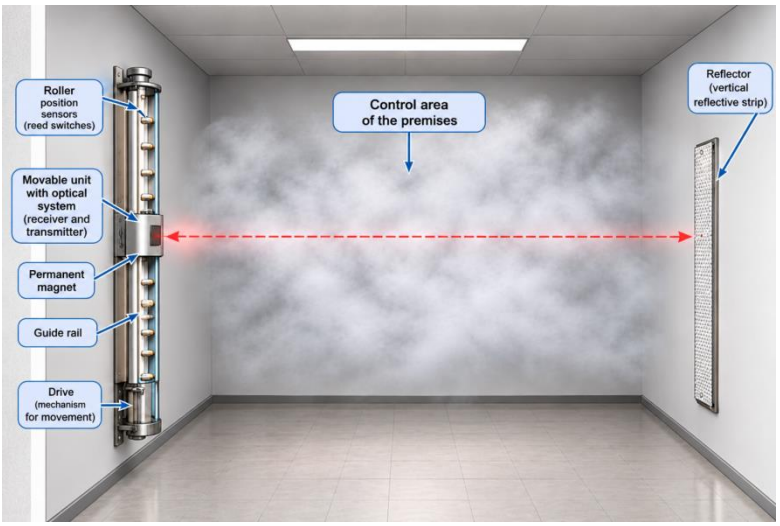

Fig. 1. Schematic of a single-component linear smoke detector with discrete control zones

Consequently, this linear fire detector architecture enables controlled positioning at predetermined intermediate points to analyze optical density at each respective elevation. This capability facilitates early smoke detection at lower heights, reduces the system response time for issuing a "Fire" alarm, and decreases the duration of uninhibited fire growth, thereby minimizing potential damage.

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