Available online at www.sciencedirect.com
ScienceDirect
Sensors and Actuators A 141 (2008) 89–96
SENSORS AND ACTUATORS A PHYSICAL
www.elsevier.com/locate/sna

# Novel sensor–actuator device for early detection of fire

Serge Zhuiykov *

*Commonwealth Scientific Industrial Research Organisation (CSIRO), Materials Science and Engineering Division, 37 Graham Road, Highett, Vic. 3190, Australia*

Received 29 January 2007; received in revised form 12 June 2007; accepted 1 August 2007
Available online 11 August 2007

**Abstract**

A new design concept of heat detectors, which introduces an ability to actuate various fire suppression systems, is described for the detection of early stage of fire. The device has been based on NiTi shape memory alloys. Application of such NiTi shape memory alloys in novel sensor–actuator allows not only a unique autonomous detection of fire at its early stage but also provides an opportunity to actuate fire suppression systems. Four basic set actuation temperatures of NiTi alloys $55 \pm 5$, $80 \pm 5$, $93 \pm 5$, and $110 \pm 5\,^{\circ}$C have been used in the proposed design. X-ray diffraction (XRD), energy-dispersive X-ray diffraction (EDX) and scanning electron microscopy (SEM) techniques have been employed for morphology characterization of the heat-treated NiTi samples. Compliance testing to the requirements of the appropriate standards revealed that the novel heat detector based on NiTi shape memory alloys with actuation temperature of $80 \pm 5\,^{\circ}$C complies with the requirements of the standards for the Class B type heat detectors. The study revealed that high sensitivity combined with actuation function provides a unique opportunity for early fire detection at maximum relative humidity of 98%. The detector is capable of sustaining impacts of up to 4 g-force of 2–50 ms duration. It is also capable of sustaining vibration from 0.5 to 200 Hz with acceleration of 4 g. The reliability investigation of the heat detection based on NiTi shape memory alloys is now in progress.
© 2007 Elsevier B.V. All rights reserved.

*Keywords:* Fire detection; Heat detector; NiTi; Shape memory alloy; Actuator

## 1. Introduction

Solid-state sensors and actuators have become increasingly important for detection and localization of fire by various suppression and extinguishing systems. In recent years particularly strong demands are emerging for those sensors which deal with early stages of fire propagation, where the temperature is still low and is usually within temperature range of 50–100 °C [1–4]. Precise detection of temperature propagation during fire development is essential for the safety improvement of various commercial and household properties. Consequently, the development of new concepts for designing relevant sensors and actuators is imperative for successful positive outcome. One approach has been developed last year and basically is based on a very simple idea to combine sensing and actuating function into one unit. Despite the obvious simplicity of this idea, it is hard to implement it on practice without materials possessing special features. Shape memory alloys seem to be well suited to such propose provided that they have to be specifically heat treated to ensure the set actuation temperature [5,6]. NiTi alloy has been gaining special attention owing to its ability to be heat treated for the set actuation temperatures among various shape memory alloys. One of the most important characteristic of NiTi alloy is the recoverable strain [7–12].

The best practical feature of the novel sensor–actuator based on the NiTi shape memory alloys is the ability not only to sense rising temperature of fire, to reduce false alarm rate but also to be directly connected to the various total flooding fire suppression systems suitable for normally unoccupied or/and unoccupiable fully enclosed spaces with flammable liquids and surfaces coated with combustion materials. Typical application of this sensor–actuator is the enclosed machinery spaces or garages.

Obvious benefits of the proposed novel heat sensor–actuator can be described by Fig. 1. Typically, different carbon monoxide, heat, smoke detectors of multi-sensors are connected to the central indicating equipment (CIE), which sometimes called *"Fire Panel"* in the conventional fire protection systems. CIE analyses all alarming signals from the detectors and initiates the

* Tel.: +61 3 9252 6236; fax: +61 3 9252 6246.
*E-mail address:* serge.zhuiykov@csiro.au.

0924-4247/$ – see front matter © 2007 Elsevier B.V. All rights reserved.
doi:10.1016/j.sna.2007.08.010

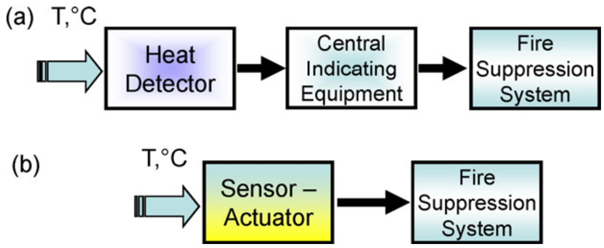


Fig. 1. Typical scheme for transfer measuring temperature of fire for actuation of the fire suppression system: (a) for conventional fire protection system; (b) for the system employed novel heat sensor–actuator.

alarm for evacuation simultaneously activating fire suppression system installed on the premises (see Fig. 1a). Detectors can be addressable or non-addressable depending on the complexity of the buildings or enclosures to be protected. In this typical scheme sensors or detectors are usually cost $20–100, CIE from $10,000 up to 50,000 and fire suppression system from hundreds to the dozens of thousands dollars. It is clear that CIE is often the most expensive element of the fire protection system and, in fact, the more sophisticated fire detectors become (multi-sensors combining two or sometimes three measuring parameters into one unit) [13] the more expensive CIE is necessary to be installed to maintain the advanced detection net. In contrast, scheme illustrated in Fig. 1b, does not require CIE at all because the sensor–actuator needs no power supply and can actuate various fire suppression systems itself. Price-wise the novel heat sensor–actuator can cost about $200–300, which is incompatible with the price of the appropriate elements of the conventional fire protection systems. Obviously these sensors–actuators cannot be employed for the fire protection of occupied areas, and consequently, compete with the different conventional fire protection systems available on the market today. However, it is our strong belief that these novel sensors–actuators have their own market niche and can compete successfully to the existing fire protection systems by the performance and by the price, including price of installation and maintenance.

Generally speaking, if a single sensor or detector is adopted for the scheme shown in Fig. 1b, it has to be redesigned in order to optimize both sensing and actuating functions independently. If it is possible to introduce in the sensing system a foreign heat-sensitive material, which possesses unique shape memory feature, both functions can be optimized simultaneously as to be sensitive to low temperatures, while the fire is still under development and be able to actuate foam, powder, aerosol, or gaseous fire suppression systems [14–17]. The NiTi shape memory alloy in these cases has to be connected mechanically with the actuation mechanism and its heat-sensitive change should sensitively modulate the superplastic properties of sensor–actuator through the junction of NiTi and actuating part of the device. The shape memory effects of NiTi alloys rely on a martensitic transformation from the austenitic $B2$-phase to the monoclinic $B19'$-phase [16]. Their high flexibility, large recoverable deformation, good fatigue life, and outstanding superplastic behavior at or around set temperatures are qualities that allow superplastic sensitive element to perform heat sensor functions not possible with other materials currently used in commercial heat detectors. This way of approach has been proven to be promising for developing novel heat sensor–actuators.

Novel heat detectors–actuators were tested to the relevant requirements of appropriate standards [18,19] in order to verify their compliance to the requirements of these standards which have been used for evaluation applicability of the conventional heat detectors to residential and commercial markets.

In this article the results of experimental work on the NiTi-based novel heat sensor–actuator are reported with emphasis on the material characterization and low-temperature sensing properties of the device.

## 2. Experimental

### 2.1. Detector preparation

General view of novel heat sensor–actuator and the shape of NiTi sensitive element are shown in Fig. 2. A binary NiTi alloy was made as a special rod by vacuum-melted, forged, and rolled sheets were then heated to 800 °C for 15 min, ice water quenched, and then cut on special pieces 1.5–2.0 mm thickness. Then NiTi alloys were additionally heat treated to provide rated activation temperatures of 55, 80, 93, and 110 ± 5 °C, respectively. This heat treatment was done in order to provide four following models of the device: 55 °C (suitable for cold areas), 80 °C (standard applications), 93 °C (custom made for special applications) and 110 °C (suitable for motor rooms and tracks). The actuation temperatures were selected to be suitable for the most of standard applications of the device. However, it is possible to heat treat NiTi to obtain any specific set temperature. All four models operate automatically similar to the conventional fire detectors with rated temperatures. Nevertheless, it is possible to modify sensor–actuator for manual actuation of the fire suppression systems or fire extinguishers.

Novel heat sensor–actuator device, as has been noticed before, has been designed to provide unique autonomous detection of fire with a fixed temperature reading and can be connected to a standard powder, aerosol, foam, or gaseous fire suppressions systems. No external power supply is required. Complied with an explosive proof junction box, this device can also be used in a safety sensor D3 for application in hazardous areas (see Fig. 2). The operation of novel heat sensor–actuator is as follows: when a heat-sensitive NiTi-based element reaches its rated temperature a spring-loaded rod mounted inside a nose piece is released. The spring moves a cylindrical shape magnet, mounted on the rod, through an induction coil. The induction coil generates an electric impulse. The impulse is transmitted to the electrical terminals and further to the fire suppression system or fire extinguisher. The device generates an electrical impulse with amplitude of 3.5 V dc at the circuit resistance of 1 Ω. The duration of the electric impulse is usually no less than 1 ms for amplitude of no less than 3.0 V dc. New detector–actuator has a length not more than 85 mm and diameter no more than 65 mm with total mass of 200 g.

Heat sensing experiments were conducted on the computerized heat tunnel capable to set various heat rates in the temperature range of 20–150 °C. Novel detectors–actuators

Download English Version:

https://daneshyari.com/en/article/749834

Download Persian Version:

https://daneshyari.com/article/749834

Daneshyari.com