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A Temperature Controller Using Power to Frequency Conversion

Stabilizator temperatury wykorzystujący zamianę mocy na częstotliwość

1. INTRODUCTION

The conversion of any physical property into frequency is the best way to enhance the accuracy of its measurement because it is frequency which can be determined with the highest accuracy. Another reason for the conversion of different variables to frequency is that the analog signal converted to train of pulses is better preserved and can be easily transferred telemetrically. A few circuits like voltage-, resistance-, and capacitance-to-frequency converters are described in textbooks [3, 6]. Nonelectronical properties like force (tension), temperature, pressure, etc. are usually converted into voltage. However, in many situations it is possible to convert their magnitudes directly into frequency by the influence of a sensitive element of a generator. For example, a multivibrator bridge with temperature-sensitive resistor can be used for versatile temperature determination, which may be telemetred, recorded or integrated [4]. Another example is the change of mass of a body, which can be converted directly to frequency shift of a quartz crystal oscillator. This method is widely used in advanced technologies in producing extremely thin layers of atoms in vacuum.

In this paper we present a convenient way of conversion of the rate of heat transfer from a wire to its ambience into frequency of electric pulses, which are supplied to the wire in order to drive its temperature about a selected value. Although such power to frequency converter, or new type of generator, may have numerous metrological applications, in this paper we will focus on its basic function as the temperature controller. Both DC and AC power sources are considered.

2. FUNDAMENTAL CONCEPT

The block diagram of the new type multivibrator to be used as precision temperature controller of a temperature sensitive resistor, R_L, is shown in Figure 1. The resistor R_L makes up one leg of Halas-Kaminski bridge, to which power can be supplied from external source V_1 in desired intervals which cannot be overlapped by the intervals of normal bridge action [2].

If $R_V \approx R_L$, the signal produced by bridge amplifier for comparator input is

$$\Delta V = \frac{V_e - 1.4V}{4} \cdot \frac{R_L - R_V}{R_V} \cdot 100\,,$$

where V_e is the excitation voltage from which voltage drop on diodes D_1 and D_2 is subtracted.

When comparator output voltage rises rapidly to the saturation voltage the monostable multivibrator, MM, starts to produce on its output single voltage pulse of a certain width which saturates the base of transistor, T. The transistor in this way connects the voltage source V_1 to the load resistor, R_L. The power is supplied from V_1 to the load resistor until the end of pulse produced by MM. When the voltage drop across R_L is higher than that produced by excitation voltage V_e then diodes D_1 and D_2 in the bridge stop to conduct. Thereby the upper part of the bridge is electrically isolated from the lower part in which R_L is energised during the time of pulse generation by the monostable multivibrator. When this pulse disappears, transistor T insulates voltage source V_1 from R_L, high voltage drop across R_L disappears and diodes D_1 and D_2 start to conduct the excitation current from V_e. Since this instant the bridge plays its normal function until the next pulse is started to heat RL again. The break between subsequent pulses depends on the following factors:

(1) the energy supplied within individual pulse, i.e. the voltage V_1 and pulse width,
(2) heat capacitance of the load resistor, and

(3) the rate of heat transfer from load resistor to its ambience, which depends on the temperature difference and quality of thermal isolation of the wire.

If the first and the second factors are fixed then one obtains a generator the frequency of which is directly proportional to the rate of heat transfer. In other words, the power dissipated by the load resistor is converted to frequency. On this principle a series of hot-wire based detectors can be constructed. Such detectors may be installed in devices and instruments like anemometer, Pirani vacuummeter, katharometer, etc. Several specific applications of the power to frequency converter will be described elsewhere. In this paper we consider most versatile and economic ways of temperature stabilisation by this method. In application of the multivibrator as the temperature controller we do not need to stabilise voltage V_1 since its fluctuations will be compensated by appropriate variations of frequency.

3. DC TEMPERATURE CONTROLLER

Low power temperature controller of a delicate filament is best performed using the schematic diagram shown in Figure 1. The peak width and voltage V_1 should be selected according to the size of the filament to assure sufficiently high frequency of the generator. The breaks between pulses should be comparable to width of pulses. If they appear much shorter than pulse width, then voltage V_1 should be increased.

A small amplitude periodic variations of the filament temperature, which is necessary for proper action of the generator, are minimised at high frequencies somewhat above the acoustic rage. A fast setting comparator as a zero-cross circuit is recommended.

4. AC TEMPERATURE CONTROLLER

If high power has to be dissipated in a large-size temperature controller then the most economic way is to use AC power supply instead of DC voltage source V_1 (Fig. 1). The AC voltage may by supplied from power network via a transformer, or directly, according to the resistance of the load resistor.

Economic circuit for this purpose should contain one heavy-duty electronic switch conducting in both directions, which would be operated by pulses from monostable multivibrator. The best solution nowadays is to use a triac which would be switched on by a LED in the nearest zero-cross of

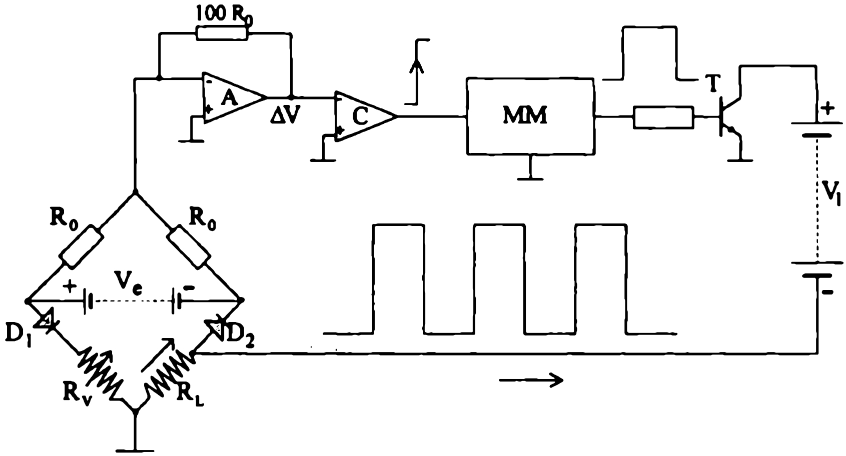

Fig. 1. Schematic diagram of new type monostable multivibrator for temperature control of load resistor (R_L) making up one leg of Halas-Kaminski bridge. A — amplifier, C — comparator, MM — monostable multivibrator

Schemat nowego typu uniwibratora do stabilizacji temperatury rezystora obciążenia (R_L) stanowiącego jedno ramię mostka Hałasa-Kamińskiego. A — wzmacniacz, C — komparator, MM — uniwibrator

AC power, rather then from the beginning of pulse generated by MM. If the pulse width overlaps a series of power waves the whole circuit will work with nearly constant period of energising of R_L.

In Figure 2 is shown schematic diagram of economic circuit with single switching device. A heavy-duty switch K_1 is closed when diode D_1 is

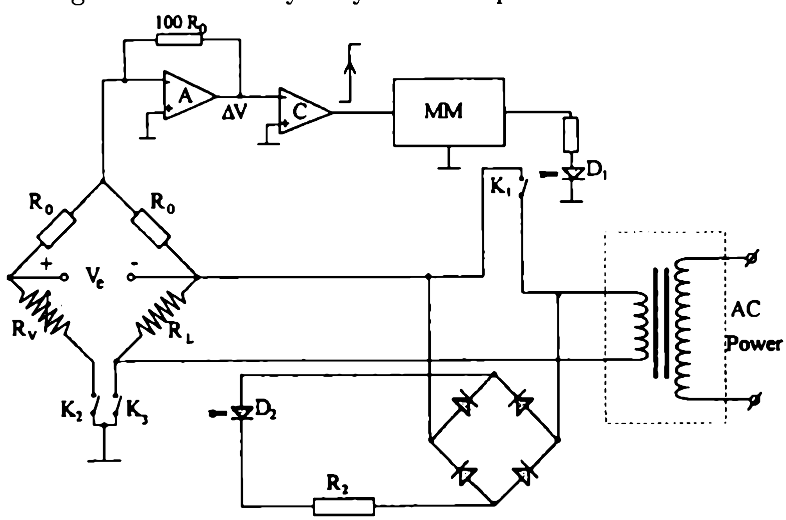

Fig. 2. Economic circuit with single switching device in AC power loop. Transformator is optional

Tani układ elektroniczny z pojedynczym kluczem w obwodzie zasilającego napięcia zmiennego. Użycie transformatora nie jest konieczne emitting light, i.e. when monostable multivibrator generates any pulse. The Halas-Kaminski bridge is modified for AC power in this way that two switching devices K_2 and K_3 replace diodes D_1 and D_2 shown in Figure 1. The switches K_2 and K_3 are simultaneously closed when diode D_2 is emitting light, i.e. when K_1 is open. Hence, the bridge plays its normal function during breaks between energising pulses. Circuit details on electronic switches K_1, K_2 and K_3 are shown in Figure 3.

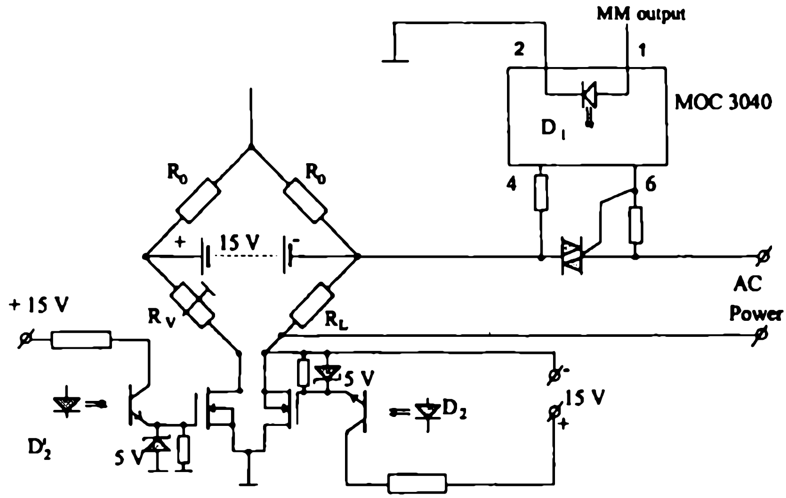

Fig. 3. Details of the switching devices K_1, K_2 and K_3 from Fig. 2 Diodes D_2 and D_2' are connected in series. Two MOSFET transistors and two optically coupled isolators CNY17 were used

Szczegóły dotyczące obwodów kluczy elektronicznych K_1, K_2 i K_3 z ryciny2. Diody D_2 i D_3 są dołączone szeregowo. Zostały użyte dwa tranzystory MOSFET i dwa transoptory CNY17

Another way of circuit arrangement for AC power is to retain former configuration of Halas-Kaminski bridge (from Fig. 1.) but a rectifier has to be used. If a half-wave rectifier is satisfactory then a thyristor may be used operated by means of LED and a zero-crossing circuit. Such devices are available as integrated circuits, e.g. MOC 3040, see Figure 4a. If power pulses should be better smoothed or they should have higher effective voltage, then a full-wave rectifier is advised. The most economic design of the bridge rectifier circuit is shown in Figure 4b. It comprises two diodes and two thyristors operated like single thyristor from Fig. 4a.

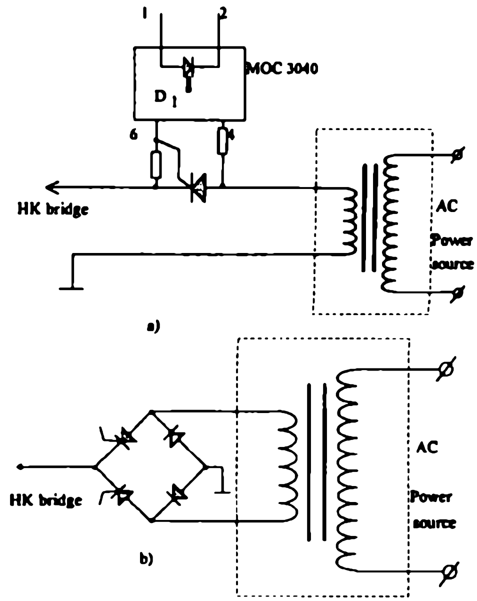

Fig. 4. Use of thyristors as switching devices: (a) half-wave rectifier, (b) full-wave rectifier. Transformator is optional
Zastosowanie tyrystora jako klucza elektronicznego: (a) prostownik jednopołówkowy, (b) prostownik dwupołówkowy. Użycie transformatora nie jest konieczne

5. MONOSTABLE MULTIVIBRATOR

Commercially available monostable multivibrators, like integrated circuit SN 74123, have been proven to be highly satisfactory. These circuits need two external parts: a resistance, R, and a capacitance, C, to arrange appropriate pulse the width of which is approximately equal to RC. Alternative solution is to arrange such circuit, on the basis of an operational amplifier, (OA), like 741. We tried a circuit the schematic diagram of which is shown in Figure 5. The desired pulse on the output starts immediately when a rapid voltage rise on the input is noticed. The capacitor C is quickly discharged by the transistor, thus the break between subsequent pulses may be extremely short.

The advantages of the OA based monostable multivibrator are as follows: (1) the TTL-series circuits require additional +5V power supply, (2) on the basis of quadruple OA, like LM 324N, one can produce a very compact and economic unit for temperature control.

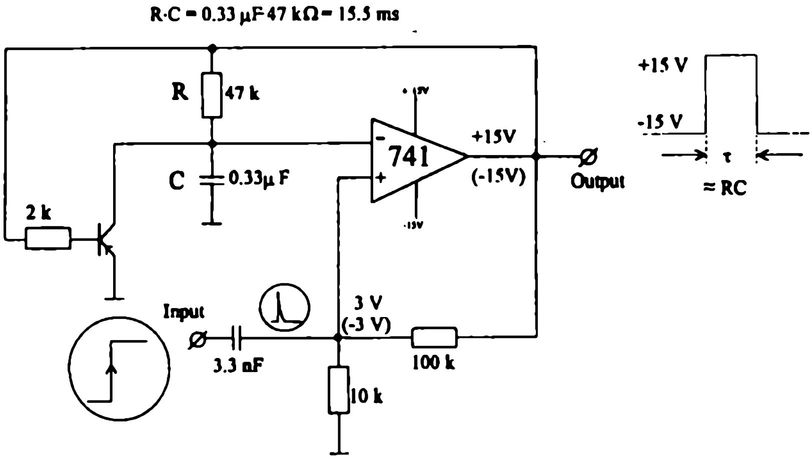

Fig. 5. Monostable multivibrator circuit based on operational amplifier 741 and p-n-p transistor (e.g. BC 393)
Obwód uniwibratora wykorzystujący wzmacniacz operacyjny 741 oraz tranzystor p-n-p (np. BC393)

6. PERFORMANCE

Detailed testing has been undertaken for the circuit shown in Figure 1. Platinum wire was used as the load resistor 40 ohms (at room temperature) while a wirewound potentiometer (47 ohms) was used as R_V. The platinum wire was wound on a Teflon frame 5 cm × 5 cm which was placed in a small box made of low thermal conductivity material (styrofoam). The temperature was measured by an electronic thermometer and recorded by means of a personal computer. A long-term plot of the recorded temperature is shown in Figure 6. High quality temperature stabilisation over periods of several hours is achieved, but the influence of major variations of ambient temperature was appreciable. Room temperature varied about 6°C, with a minimum of 17°C at 2:00 a.m.

The remaining circuits designed for AC power were tested using a heating with low temperature coefficient (nickel/chromium alloy). Nevertheless fascinating qualitative results were obtained. The coil was installed in a ceramic insulator, its temperature was regulated fluently from room temperature to about 700°C. Since the spirale had about 70 Ω resistance, no transformer was needed.

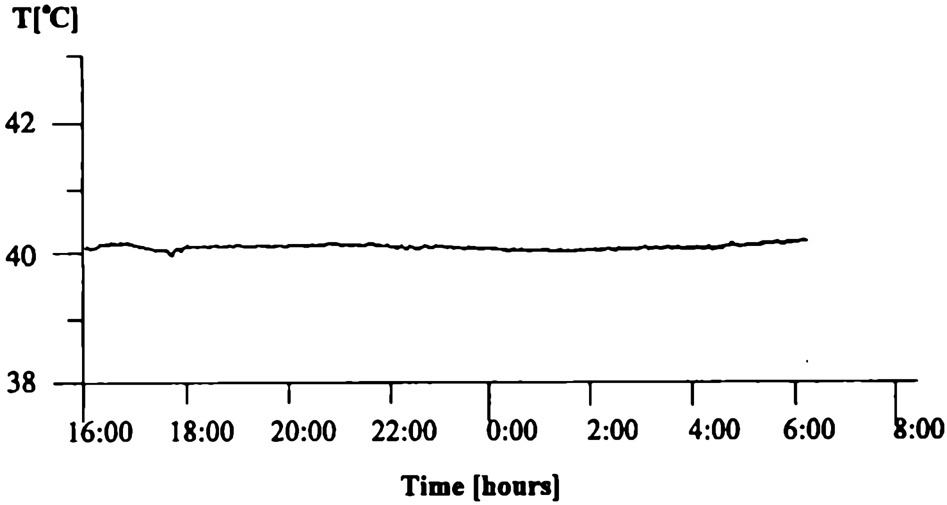

Fig. 6. Long-term test of temperature stabilisation
Długoczasowy test stabilizacji temperatury

7. DISCUSSION

The circuit described in this paper can be considered a self-pulsating generator, or astable multivibrator, the frequency of which depends on the heat transfer between load resistor and its ambient. This property offers numerous metrological applications of this circuit, which were listed in our previous paper [2]. The frequency measurement, rather than analog signal, will enhance the sensitivity and precision of H-K bridge based devices.

It is worth noting that the temperature controller of this type is extremely useful in devices where space available is limited and where it would be difficult to install a thermocouple or other sensing thermometer. The circuit described here appears to be more versatile than previously described H-K bridge based circuits [1, 2].

A temperature control system for use in an electronical heating device wherein the heating element also functions as the temperature sensing element was invented by Orosy and Matlen [5]. However, the insight into their patent description convinced us that our circuit is simpler and it offers, in addition, power-to-frequency conversion.

ACKNOWLEDGEMENTS

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STRESZCZENIE

Zamiana mierzonych wielkości fizycznych na częstotliwość jest metodą często stosowaną w celu zwiększenia dokładności pomiaru. Zwiększenie dokładności uzyskuje się dzięki temu, iż pomiar częstotliwości może być wykonany prostymi środkami z bardzo dużą dokładnością, zależną jedynie od czasu trwania pomiaru.

W niniejszym artykule przedstawiono prosty sposób konwersji ilości ciepła rozproszonego przez drut oporowy na częstość impulsów elektrycznych dostarczonych do drutu, przy jednoczesnej stabilizacji jego temperatury. Schemat ogólny stabilizatora pokazano na rycinie 1. Urządzenie wykorzystuje ten sam element wykonany z drutu oporowego do rozpraszania ciepła i do pomiaru temperatury, bez konieczności użycia termopary. Przedstawione zostały aplikacje dla małych i dużych obciążeń oraz wersje dla zasilania drutu oporowego prądem stałym i zmiennym (Ryc. 2–3). Urządzenie charakteryzuje się prostotą konstrukcji, wielką liczbą możliwych zastosowań, spośród których warto wymienić poza samą stabilizacją temperatury: pomiar ciśnień, pomiary przepływu, analizę termiczną itp. Wyniki testu stabilizacji temperatury przedstawiono na rycinie 6.