Microprocessor-based Apparatus for Electrical Stimulation of Ruminant Meat

Ivan Maslinkov[1] and Krassimir Kolev[2]

Abstract – **A microprocessor-based device for electrical stimulation of ruminant meat is designed by AT89C2051 microcontroller. The paper considers the action principle by structural and time diagrams of ruminant meat stimulator. The microprocessor-based apparatus stimulates the meat with a safety low voltage. The designed apparatus has six different stimulation modes. The schematic diagram and an algorithm description of designed apparatus are given. Analyses and recommendations are made.**

Keywords – **Electrical stimulation, Microprocessor-based apparatus, Meat of ruminant animals.**

I. Introduction

Electrical stimulation of ruminant meat is a world-wide established operation where electrical current (pulses) of certain parameters [1÷4] is applied through the carcass (or parts thereof). As a result, the technological cycle is shortened, the quality of meat and the hygiene are improved, etc. [1].

Advancements in the electrical engineering, electronics and automation resulted in an increased number of mass produced and marketed devices (or assemblies and parts for such devices) equipped with standardized inputs and outputs, allowing for programming (setting up) of wide ranges and various modes and fitted with built-in logical functions, etc. [2,3].

The aim of this paper is to present a microprocessor-based device for electrical stimulation of ruminant meat incorporating a mass produced microcontroller AT89C2051.

II. Design diagram and operating principle

Requirements to parameters of the device for electrical stimulation using low (amplitude of electrical pulses up to 100 ÷ 110 V) voltage are [3]:

- process duration is within 60 s ;
- voltage pulse amplitude (U_{MAX}) minimum 60÷70 V ;
- current pulse amplitude minimum 50 mA ;
- pulse duration (t_{PLS}) about 5÷10 ms ;
- recommended pulse repetition frequency (f) 10÷100 pulses/s, no operation under 10 pulses/s since the carcass contracts at each pulse and the contractions, particularly in the beginning, are strong and bone fractures may occur ;
- rectangular pulse shape.

It should be noted that the shape of the pulses is not of significance but the most commonly used shape is rectangular as it is easier to obtain [3, 4]. The polarity of the pulses is also of no significance, however (heteropolar) pulses are recommended having alternating polarity to reduce the impact of polarization effects [5].

The maximum output current for the low-voltage stimulators does not exceed 1 A [3, 4] which must be borne in mind when selecting the stimulator components.

There are also other requirements to the electrical stimulation apparatuses, such as:

1. In the first 5÷7 s the pulse amplitude must increase from 10÷20 V to 60÷70 V, and the by the end of the stimulation it reaches 80÷90 V (or up to 110 V, if the effective voltage value is safe) [5]. This is to avoid the violent and abrupt contractions of the carcass at the start of the stimulation;
2. In [3] there is a recommendation to stimulate using electrical pulses with gradual (the said paper specifies exponential) reduction in their frequency from 100 pulses/s at the start of the stimulation to 10 pulses/s at its end since muscle fatigue occurs during the process (and they cannot respond effectively to the higher frequencies) and habituation to unvaried stimuli. It is advisable to reduce the frequency when the amplitude is increased.

Fig. 1 shows the block diagram of the proposed microprocessor-based apparatus, and Fig. 2 shows time-diagram of its output electrical pulses (u_{out}) with which the meat is being treated.

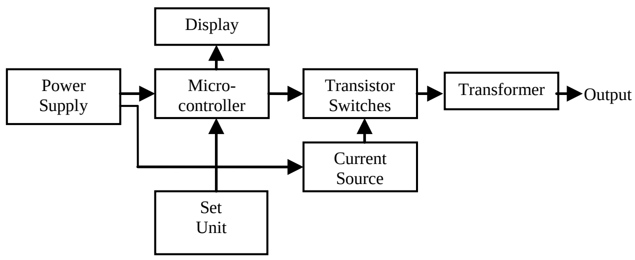

Fig. 1. Block diagram

Both figures illustrate the principle of operation of the proposed apparatus where the stimulation was performed with rectangular heteropolar pulses

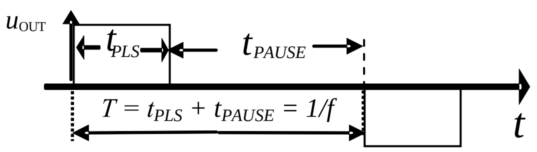

Fig. 2. Time-diagram of output pulses

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The apparatus in Fig.1 consists of:

- power supply which provides safe continuous voltage of 9 V for the operation of the stimulator;
- microcontroller to control and form the string of pulses (t_{PLS}) and pauses (t_{PAUSE}) between them as well as the frequency of pulse repetitions (f) to control the transistor switches;
- transistor switches which perform switching action and produce the output rectangular pulses;
- current source for constant safe charge;
- set unit for selecting the stimulation mode;
- display to show the selected stimulation mode.

III. DESIGN OF THE APPARATUS

The second voltage which must supply the transformer is selected so as to ensure the minimum of the pulses' amplitude at the output of the apparatus ($U_{MAX} \geq 60 \div 70$ V) while their effective value (U) must not exceed the safe 24 V. The latter depends on the amplitude, duration, shape and the repetition frequency of the pulses used [5]. The following formula applies:

$$U = U_{MAX}\sqrt{f.t_{ИМП}} \qquad (1)$$

If, for example, $U \approx 24$ V, $U_{MAX} \approx 90$ V and $f = 15$ pulses/s are to be selected, the pulse duration for this configuration is $t_{PLS} \approx 5$ ms. For this configuration it is better to increase the duration $t_{PLS} \approx 7$ ms in order for it not to be at the lower limit and to decrease the frequency (f = 12 pulses/s) and the amplitude of the output pulses (U_{MAX} = 80 V). It is apparent that the power of the transformer is under 50 VA and the price is around EUR 25 [6].

It is advisable that the transistor switches, in addition to conforming with the specified current and voltage, be able to switch on and off with small losses, i.e. to have the so called soft switching.

Each electrical apparatus needs a suitable housing and power supply of 9 V DC which in this case are expected to cost around EUR 35.

The minimum pulse amplitude value provided in the beginning has any significance only if the output current is being monitored in the stimulator. In fact, it would be more precise to state that only by ensuring minimum value of the current density will it be possible to provide quality stimulation [5]. The design of the microprocessor stimulator is based on a low-budget widely available microcontroller AT89C2051 by Atmel at a price of EUR 1 [6]. The AT89C2051 provides the following standard features: 2K bytes of Flash, 128 bytes of RAM, 15 I/O lines, two 16-bit timer/counters, a five vector two-level interrupt architecture, a full duplex serial port, a precision analog comparator, on-chip oscillator and clock circuitry. The Port 1 is an 8-bit bi-directional I/O port. Port pins P1.2 to P1.7 provide internal pull-ups. P1.0 and P1.1 require external pull-ups. P1.0 and P1.1 also serve as the positive input (AIN0) and the negative input (AIN1), respectively, of the on-chip precision analog comparator. The Port 1 out-put buffers can sink 20 mA and can drive LED displays directly. When 1s are written to Port 1 control register, its pins can be used as inputs. When pins P1.2 to P1.7 are used as inputs and are externally pulled low, they will source current because of the internal pull-ups [7]. The basic schematic diagram of the stimulator is shown on Fig.3. The microcontroller IC1 (AT89C2051) is programmed to generate rectangular pulses at its outputs Rx and Tx upon pressing the start S1 button. These pulses control the MOSFET transistors T1 (IRF540) and T2 (IRF540) which switch the voltage over to the primary winding of the TR1 transformer. The transformer is a step-up line audio with transformer ratio of ten and power of 30 W. The magnitude of the output current is determined by a current source consisting of the transistor T3 (BD140) and the passive components R1, R3 and C6. The current source charges the capacitor C6 to a safe charge. The voltage of this capacitor is used to supply the transistor switches T1 and T2. The circuitry shaping the output pulses is designed as a traditional push- pull topology converter with transformer galvanic isolation. The maximum energy transferred for a switching cycle is:

$$E = \frac{C.U^2}{2}, \qquad (2)$$

where C is the capacity of capacitor C6, and U is the supply voltage.

With the values thus selected, the maximum transferred energy is $E=4.05mJ$, which is way under the permissible threshold value of 300мJ for the electrical safety of electrical stimulators [8]. This ensures that the device is safe as it provides reduction of the transferred energy for each switching cycle.

A question may be asked as to why a microcontroller is being used to generate pulses when this can be done using timer integrated circuits of the 555 type. In addition to the selected controller being sold on the market at a price comparable to the one of the timer integrated circuits, it is possible to introduce additional software-based features and various stimulation modes. Moreover, in case of fault, the microcontroller stops the execution of the system software and the generation of pulses to the transistor switches, i.e. the frequency and the cycle of pulses do not depend on external time-setting components.

The S2 button (PROG) is used to select among the six stimulation modes (1÷6) which are displayed on the 7-segment LED indicator LD1. If no mode has been selected, the indicator displays zero and the simulator cannot be started. After selecting a mode, the stimulation process is initiated using S1 (START). The duration of the stimulation process is 60 seconds according to the technology [5].

The pulses are of duration t_{PLS} and variable frequency f in order to form variable intensity of meat treatment for the six different modes. Fig. 4 shows the diagrams for the intensity of treatment for the different program modes.

LED D2 indicates that the stimulator functions properly. The C3 and R5 group is standard for the processor and produces the signal for the initial resetting after the switch on of the power supply.

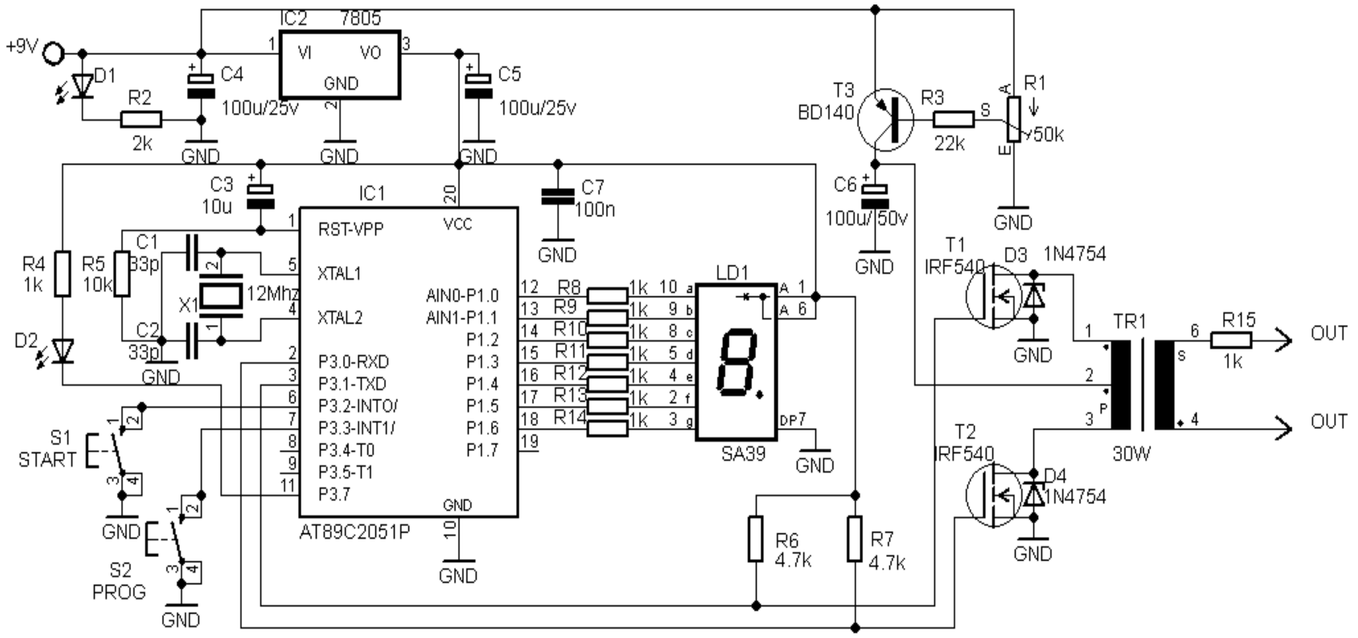

Fig. 3. Schematic diagram of the microprocessor stimulator

A 12 MHz quartz resonator has been selected and the internal system microprocessor clock is with precise value of 1 μs for all microcontroller subsystems.

The value of the active electronic components of the presented ruminant meat stimulator is under EUR 10 [6]. Hence the total costs of the materials do not exceed EUR 75. If the labor costs are to be taken into account, the total value of the designed multifunctional apparatus can reach around EUR 110.

The software consists of a main program and an interrupt service routine.

The main program performs initialization, allows interrupts of the timer and the external inputs P3.2 and P3.3. The interrupt service routine controls all processes in real time such as monitoring the stimulation time, servicing the buttons and generation of rectangular pulses at outputs P3.0 и P3.1. The internal timer 0 operates in mode 3 where its clock frequency 1 MHz is divided by 256 [9]. The timer 0 generates an interrupt each 256 μs. Interrupts are counted and the circuitry is controlled. The program actually comprises a finite-state machine which activates outputs P3.0 and P3.1 in sequential order. The P3.0 output is established at high level every odd cycle of t_{PLS} generation, and the P3.1 output at high level every even cycle of t_{PLS} generation.

The value of t_{PLS} is set in a table format based on the number of interrupts from timer 0 for each stimulation mode based on the desired pulse duration. The numbers of interrupts are equal to the desired t_{PLS} in ms multiply by 1000 and divide to 256. For example, for t_{PLS} =7 ms we set 27 interrupts for timer 0 by look-up table in the program read only memory on AT89C2051. The number of interrupts forming the pause cycle are equal to $1/f$ multiply by 15625 divide to 4 minus number of interrupts for t_{PLS} .

Processing time is fixed for all operation modes and is obtained after producing 234375 interrupts.

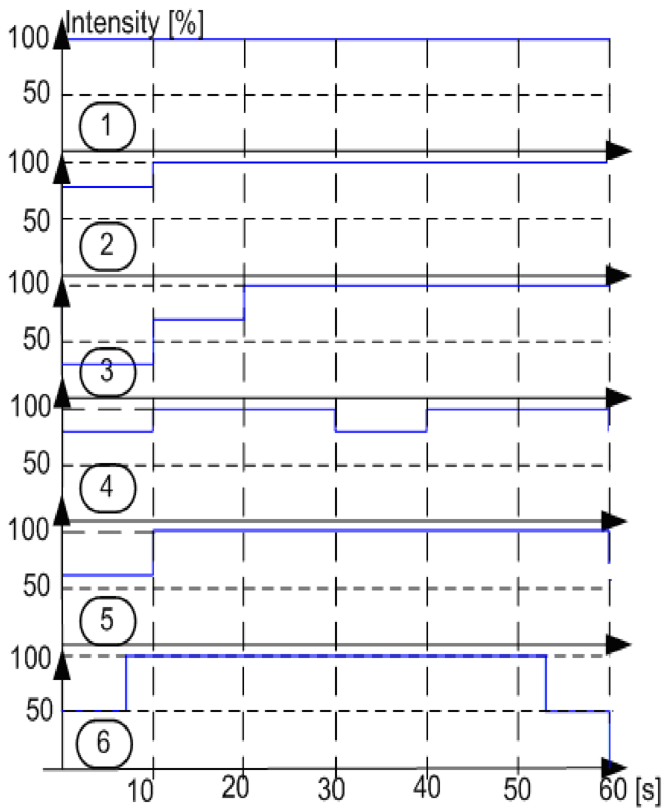

Fig. 4. Operation modes

The program allows for the processing to be interrupted by pressing again the S1 or S2 buttons. Figure 5 shows the algorithmic diagram for the interrupt service routine.

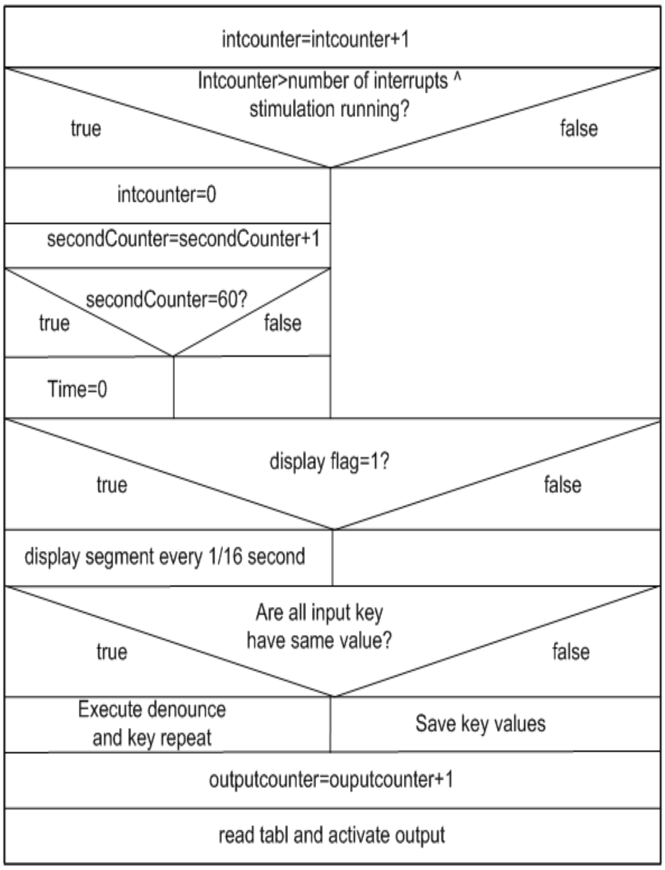

Fig. 5. Algorithmic diagram for interrupt service routine

The intcounter monitors the number of pulses per second. The secondCounter is used to set and monitor the fixed processing time. At any time, using the S1 and S2 buttons, it is possible to interrupt the servicing of the timer and stop the stimulation process. Based on the produced timer interrupts, values controlling the outputs for the next produced cycle are loaded from a table located in the internal program read only memory.

The main program checks whether a specific button has been pressed. The program operates in an infinite loop until a button is pressed.

Firmware of the proposed microprocessor-based apparatus is written in C programming language using freeware Crimson editor [10] and burn to the microcontroller by using Willar SP200S programmer [11].

Before operating the apparatus, the personnel must be made aware of the electrical safety precautions and only a certification safe double galvanically decoupled source of 9 V dc with power of 50 W must be used [12]. The selection of transistors and diodes is not crucial and other types may be used considering switching currents and supply voltages.

IV. Conclusion

This paper discusses a microprocessor based design and configuration of an apparatus for electrical stimulation of ruminant meat built using a mass produced, widely available and low-budget microcontroller AT89C2051.

The operating principles and manner of its construction have been explained. The presented stimulator supports six program selectable stimulation modes. Since the program modes are implemented through software, it is possible, without making changes in the circuitry, to expand the set programs up to fifteen. If a second seven segment indicator element is added, the selectable programs can be increased up to ninety-nine. The cost of the proposed device is around EUR 110.

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