COCA: an On Line Control IC for Watch Stepping Motors

Ermanno Bernasconi, *Member, IEEE,* Jean-Pierre Wattenhofer, *Member, IEEE,* Pierre-André Farine, *Member, IEEE,* Daho Taghezout[1]

Asulab SA, 2074 Marin, Switzerland, [1] ETA AG, 2540 Grenchen, Switzerland

Abstract - An on-line control IC for watch stepping motors that allows significant power savings is presented. This system enables the open loop control of a wide range of motors. This leads to a significantly longer battery life, enables to cut motor production costs and to increase system reliability. Particularly, the COCA IC offers an extreme adaptability to the different motor types that can be driven, thanks to a programmable correlation function, and performs an immediate missed-step recognition and recovery.

I. Introduction

The essential development objectives in the market of analog wrist watches and clocks are increasing the battery life, cost reduction, the realisation of flatter movements, the development of lithium battery powered systems and a reduction in noise levels. Until now motors and integrated drivers have been developed and optimized separately, and we are presently facing limitations that can only be overcome by a joint effort of designers and motorists.

The integrated circuit we present here achieves new performances embodying the knowledge of motors, stored in a ROM, and assessing precisely and constantly its dynamical behaviour so as to deliver the exact amount of energy needed.

Some information on the actual state of the art is presented in section II, where we will describe some of the main problems in the domain. In section III we will present the basic control principle and describe how we implemented the system equations in the IC. We will describe the normal step and the missed step procedures in section IV. Section V will present the performance of our system and section VI concludes the paper.

II. STATE OF THE ART

In current analog watch ICs powered by 1,5 V batteries, the motor step is often obtained through a voltage pulse of constant width. The width of this pulse must be determined so as to ensure a successful step under the worst conditions, that is, with a minimum voltage. This approach implies a series of drawbacks. First of all, almost through the entire battery life an excessive current is drawn with a voltage higher than the minimum value. Moreover, a higher driving torque is only seldom required and, for a step obtained under normal conditions, too much energy is expended. Finally, driving a motor under light charge conditions with a greater than needed torque leads to an excessive acceleration and an extra oscillation, which causes reduced system stability and decreased reliability.

The first means to overcome these drawbacks is to use a voltage burst instead of a continuous pulse, therefore limiting the current rise in the motor coil. The second means is to implement an indirect control system that, i. e. when a missed-step is detected, sets the pulse width to the maximum value, recovering the initial minimum value step-by-step at slow pace (e. g. 1 Hz). Unfortunately an indirect system cannot deal with a great friction torque or a weak detent torque.

III. BASIC EQUATIONS OF THE CONTROL SYSTEM

The system presented here realizes a direct control of a one-phase Lavet motor working as a stepping motor. The goals of the control system are to minimize power consumption under no load, to deliver a high driving torque when needed and to adapt the mechanical energy supplied by the motor to the actual mechanical load. The electrical motor consumption is minimized with a specific current level, called reference current, and with a certain pulse duration (see [1]). In our system the reference current level is fixed and only the pulse duration adapts itself to the actual load.

The motor is fed by a voltage pulse with an amplitude U_p. The current I_b flowing through the coil is periodically measured and compared to the reference value I_{ref} (sampling frequency $f_s = 1/D$) so as to be kept around the I_{ref} value. The parameter that decides the duration of the motor pulse is the mechanical energy $W_m(t)$ delivered by the motor at time t

$$W_m(t) = W_e(t) - W_j(t) - W_{mag}(t) \qquad (1)$$

where $W_e(t)$ is the electrical energy supplied to the motor, $W_j(t)$ is the Joule energy dissipated in the coil and $W_{mag}(t)$ is the magnetical energy stored in the coil. The control algorithm implemented by the IC computes the normalized quantity $W_r(t)$, this being proportional to $W_m(t)$, see [1] and fig. 1

$$W_r(t) = W_m(t) / D \,.\, R_b \,.\, I_{ref}^2 = p \,.\, C_1 - C_2 \qquad (2)$$

The numbers C_1 and C_2 represent the state variables of an up-down counter switched on at time t_0. The mechanical energy delivered by the motor is described by a function of the type shown in figure 2. The time at which this function crosses the reference energy W_{ref} increases proportionally to the load torque T_{fx}.

IV. Normal and Missed Step Procedure

The normal step procedure is the usual case, when the motor is not submitted to an excessive charge and does not undergo a mechanical shock. The coil current is sensed, measured and compared to the reference value during the entire motor pulse, realizing the pseudo-constant current control, thanks to a programmable current source, a current extractor and a dynamic comparator. A counter detects the instant at which the mechanical energy supplied by the motor equals the reference value and at this time addresses a ROM that contains the correlation function. This ROM outputs the total supply time varying between the typical values 3 and 10 ms.

In case of severe load conditions or mechanical shocks the Lavet motor may be in a counter-phase situation. The control detects the problem within the first ten milliseconds and reacts by sending to the motor two high-energy pulses, each lasting at most 15 ms. In this way, we realize an immediate missed-step detection and recovery. Unlike current motor control ICs, COCA only stays for a short time in the missed-step procedure, recovering as soon as the next second the minimum energy pulse value.

V. Typical Characteristics of the IC

The IC has been designed for low voltage and low power operation, also minimizing the chip dimensions. The consumption predictions are 150 nA under 1,5 V, die surface is 5,4 mm^2 in ALP2LV, a 2µm CMOS low voltage technology of EM Microelectronic-Marin. A chip microphotograph is shown in figure 3. With this IC, the motor achieves a consumption of 450 nAs.

With the present chip the user disposes of a six bit EEPROM for the quartz oscillator inhibition trimming and of another six bit EEPROM for the current source trimming. The temperature compensation of the latter can be trimmed over three steps via the metal mask. The reference current is programmable over a wide range of values. This is programmed automatically inside the IC during the test procedures by the injection of an external current. Moreover, the circuit offers a great flexibility due to the metal mask programmable ROM, which is used to tailor the system to the motor characteristics. The correlation function $tau_x = f(t_x)$ is stored in this ROM of a size of 160 x 8 bit. This is an important feature, in comparison with competitive products.

The circuit features fast testing mode and battery end of life detection (EOL). In EOL mode the motor is driven with a constant width voltage pulse with no control at all because of the insufficient battery voltage level.

VI. Conclusion

The COCA control system introduces a major breakthrough in watch stepping motor performance. This having been made possible due to a close collaboration between designers and motorists so that it has been possible to optimize overall system performance.

With this control, we have been able to reduce the motor current by a fourth to a third. Overall power consumption will be reduced accordingly, thus increasing battery life and reducing chemical environment pollution. In addition, this control is more flexible than others ICs recently presented.

References

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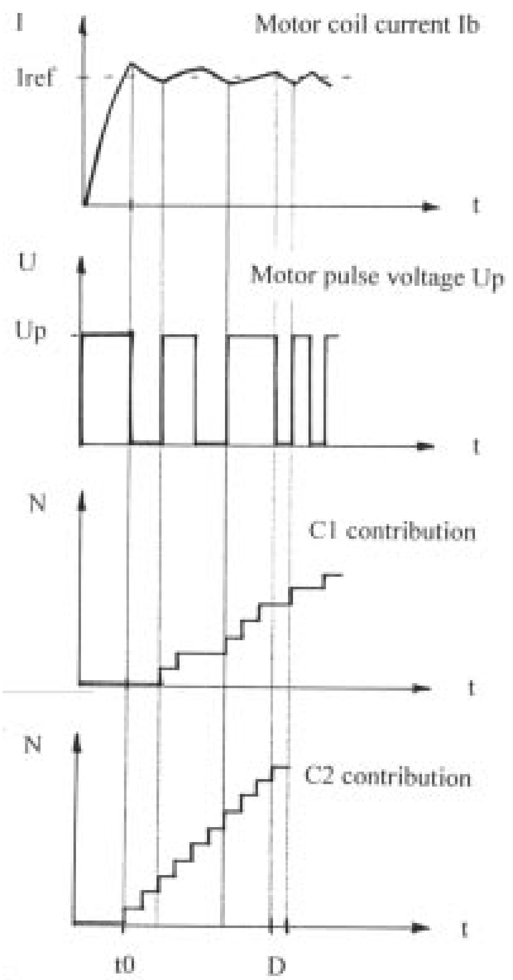

Figure 1 - COCA, principle of operation

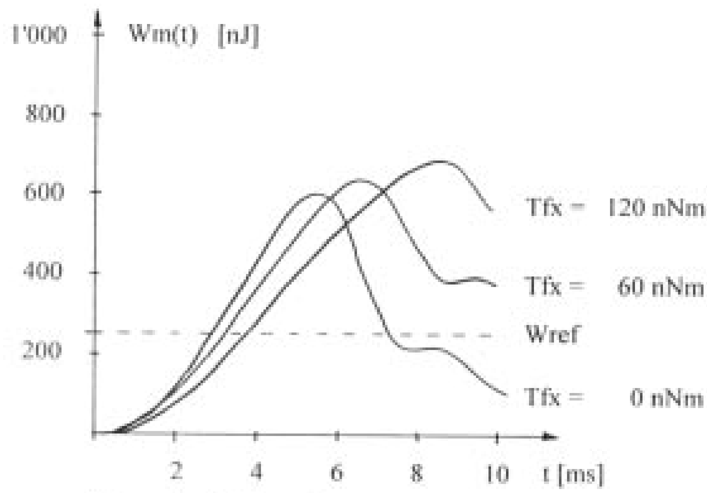

Figure 2 - Delivered mechanical energy

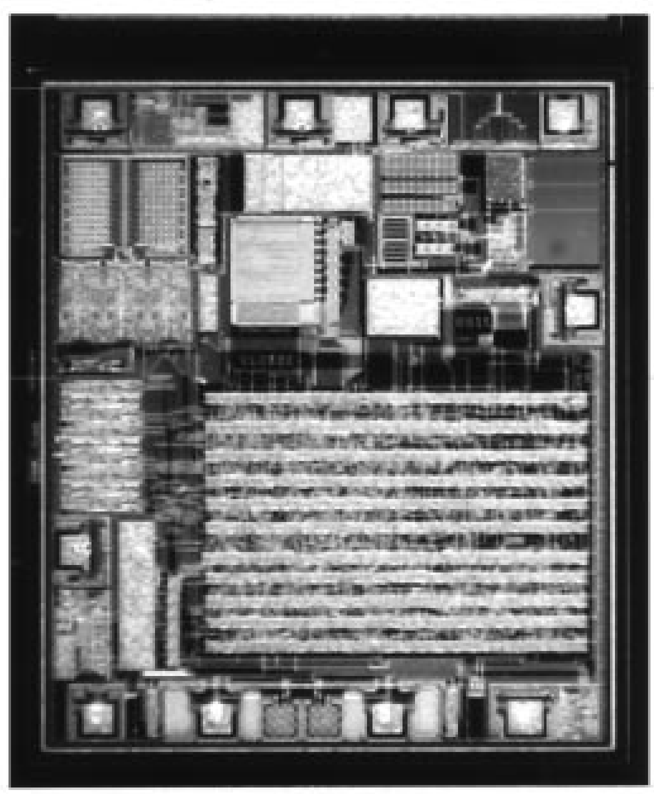

Figure 3 - COCA V1050 chip microphotograph.
Die dimentions are 2.1 mm x 2.5 mm in CMOS
2μm low voltage technology ALP2LV