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Attiny85 controlled watch winder for self-winding mechanical watches

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Abstract

In mechanical self-winding movement, the center-anchored Rotating Weight rotates about its axis with physical motions of the hand. It thereby winds the mainspring only when worn and stops during lay-offs. A watch winder re-creates the physical motions to maintain the beat in the caliber, when not worn. The paper proposes a residential tourbillon watch winder for self-winding mechanical calibers. The main objectives of this paper are to minimize the working time of the winder and consequently optimize its power consumption. A significant trade-off between the winding and unwinding ratios of the mainspring is ensured, maintaining a higher former ratio using a single-phase 9 RPM Permanent Magnet Synchronous Motor. The proposed model states the sufficiency of the winder to work only for 60% of the time. The model uses Watchdog timer to rekindle Attiny85 Microcontroller from sleep mode for scheduling the working time of the winder. The disclosed model is deployed to a Seiko (7S26A) caliber and a Citizen (8200A) Caliber for a period of 26 days to validate the working. The results show that the proposed model with the Seiko caliber requires 41.1 h for winding while the commercial models require 70.99 h. Similarly with the Citizen Caliber, the proposed watch winder requires only 28.8 h which is 21.11 h less than the time required by commercial models.

Keywords: Attiny85, Watchdog timer, Synchronous motor, Watch winder, Self-winding calibers, Gear ratio, Winding rule, Tourbillon

Introduction

A watch winder is a device that winds the mainspring of self-winding mechanical caliber when the watch is not worn. On the basis of the winding mechanism, winders are classified as Oscillating and Tourbillon. The Oscillating watch winder oscillates back and forth using power drive mechanism with 10–12 RPM, by recreating the hand gestures of a human. The winder creates rapid swifts of the oscillating weight to simulate the startling movements that develop in the watch when wore in hand [1]. However, such rapid swifts critically damage the jewels and pivots of the gears. Hence, Tourbillon mechanism is considered to be ideal, as it rotates about a full axis for winding the caliber. It also causes the least tears and maintains a better accuracy in the caliber [2, 3]. But the existing tourbillon winders work excessively without any power optimization. Hence, this paper proposes a tourbillon-based winder that works for a shorter duration with higher power optimization using Permanent Magnet Synchronous Motor and Attiny85 micro-controller. Attiny85 is a low power micro-controller with advanced RISC design. With 512 bytes of EEPROM, 8 kilobytes of flash memory, 256 bytes of SRAM and 32 registers, Attiny85 has an internal oscillator and an 8-bit timer. The controller has three interrupt sources with a programmable Watchdog timer. Attiny85 works in three modes: power down mode, ADC noise reduction mode and idle mode [4].

Permanent Magnet Synchronous Motor has been chosen for this model as the speed of this motor is unchanged with any change in load [5, 6]. Also, by determining the initial rotor position of the Permanent Magnet Synchronous Motor, sensor-less speed control can be achieved [7–9]. Further, the Permanent Magnet Synchronous Motors operate at a better power factor that results in reduced losses in the power system [10–12]. Considering the low cost and easy-availability of low-speed Permanent Magnet Synchronous motors, a single-phase 9 RPM Permanent Magnet AC Synchronous Motor is chosen for winding the caliber.

Related work

Traditional tourbillon mechanisms use detachable padded mandrel that holds the watch intact. The mandrel is coupled with the shaft of the low-speed electric motor that rotates recursively until the motor is de-energized [13]. Modern-day tourbillon watch winder uses two longitudinal rollers, placed parallel to each other, on which the watch is placed in a cylindrical case. One of the rollers is driven using an electric motor and the watch in the case rotates about its axis due to the frictional forces between the rollers. Resultantly, the whirl motion of the oscillating weight is achieved. A sensor is placed accordingly to compute the number of revolutions and it is displayed to the user using a display panel. This “Tourbillon” effect appreciably maintains the accuracy of the caliber by reducing the impact of gravity [14]. With additional features, controllable watch winder adopts the tourbillon concept with an inter-rotating watch case which is controlled by a microprocessor. The microprocessor counts the number of rotations, records and presets the latency between each rotation [15].

Methods

60% winding rule for the winder introduced this rule is validated using two calibers (SEIKO 7S26A and CITIZEN 8200A) by determining their winding and unwinding ratios. The architecture of this model is then fabricated on PCB for customization. The working schedule of the winder with 9 RPM Permanent Magnet Synchronous Motor is formulated to obtain the results. From the results, the 60% winding rule is proven to work flawlessly with all calibers having 40-h or higher power reserves.

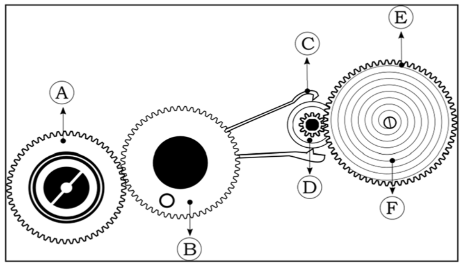

Fig. 1 Winding gear train of SEIKO7S26A Caliber. **A** The oscillating weight or the rotor, **B** First reduction wheel, **C** Pawl Lever, **D** Second Reduction wheel, **E** Ratchet Wheel, **F** Mainspring, contained in the barrel (attached to the Ratchet Wheel)

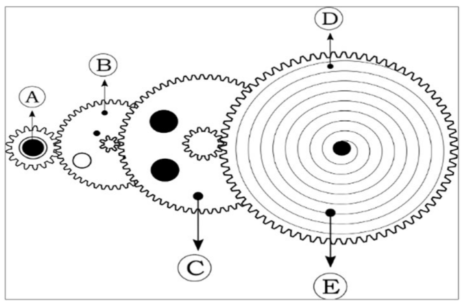

Fig. 2 Winding gear train the CITIZEN8200A Caliber. **A** The oscillating weight or the rotor, **B** Pawl Winding Wheel, **C** Reduction Wheel, **D** Ratchet Wheel, **E** Mainspring, contained in the barrel (attached to the Ratchet Wheel)

SEIKO7S26A caliber

With yoke winding mechanism, SEIKO 7S26A is a 40-h, 21-jewel day-date caliber with 21,600 beats per hour. Its magnetic resistance is 4800 A/m (60 gauss) and has a lift angle of 53°. It has a pallet lever escapement with nickel annular balance and Etachron regulator. The salient feature of "Magic lever mechanism" enables the winding of the mainspring by bidirectional rotation of the oscillating weight and it has become the key reason for considering this caliber.

In SEIKO7S26A movement, the Oscillating Weight (rotor), First Reduction Wheel, Pawl Lever, Second Reduction Wheel, Ratchet Wheel, the Click and Mainspring Barrel are constituted for winding the mainspring. Click is a thin metallic lock that prevents spontaneous unwinding (Figs. 1 and 2).

(1) The winding and the unwinding ratio

In the self-winding watches, both winding and unwinding take place simultaneously. So, it must be ensured to maintain winding ratio higher than unwinding ratio, when placed in the winder. The gear ratio and data related to the winding of the mainspring is physically inspected and stored for calculation.

(2) Gear ratio of oscillating weight to ratchet wheel

In SEIKO 7S26A movement, one rotation of the oscillating weight in either direction corresponds to 0.0064 rotation of the mainspring barrel. 154.8 turns of the oscillating weight corresponds to one full rotation of the ratchet wheel, winding the mainspring by 0.16%. For a 40-h power reserve, it takes 8 turns of the ratchet wheel to fully wind the mainspring [16]. Hence, 1238.4 turns of the oscillating weight is required to fully wind the mainspring.

Let $\mathfrak{N}_1, \mathfrak{N}_2, \mathcal{T}_1, \mathcal{T}_2$ denote the rotations of the driver gear, rotations of driven gear, tooth of driver gear and tooth of the driven gear respectively. Then,

$$\text{Gear Ratio is } \frac{\mathfrak{N}_1}{\mathfrak{N}_2} = \frac{\mathcal{T}_2}{\mathcal{T}_1} \tag{1}$$

$$\Rightarrow \mathfrak{N}_1\mathcal{T}_1 = \mathfrak{N}_2\mathcal{T}_2 \tag{2}$$

Let $\mathcal{OW}, \mathcal{FRW}, \mathcal{SRW}, \mathcal{PL} and \mathcal{RW}$ denote the Oscillating Weight, First Reduction Wheel, Second Reduction Wheel, Pawl Lever and Ratchet Wheel, respectively.

The following four Gear Ratios are calculated using the basic specifications of SEIKO 7S26A, Eqs. (1) and (2).

From Table 1, the gear ratio of the oscillating weight to ratchet wheel is found to be 154.8:1.

(3) Time taken to wind a completely unwound main spring

No. of turns of the rotor to completely wind the main spring = 154.8 × 8 = 1238.4

Winding speed (RPM) = 9

$$\text{Total Time Taken} = \frac{1238.4}{\text{RPM} \times 60}$$

Total time taken is 2.29 h.

Table 1 Gear ratio

Gear ratio	Driver gear	Driven gear	Ratio
$\mathfrak{R}_1$	$\mathcal{OW}$	$\mathcal{FRW}$	1:1
$\mathfrak{R}_2$	$\mathcal{FRW}$	$\mathcal{SRW}$&$\mathcal{P}$L	30:1
$\mathfrak{R}_3$	$\mathcal{SRW}$	$\mathcal{RW}$	5.16:1
$\mathfrak{R}_4$	$\mathcal{OW}$	$\mathcal{RW}$	154.8:1

(4) Time taken to unwind a completely wound main spring

From the manufacturer's (SEIKO 7S26A caliber) claim, the time taken to unwind a completely wound mainspring is 40 h. Hence, the power reserve is 40 h [16]. Therefore in 1 min, 0.04% of the mainspring gets unwound.

(5) Ratio between winding and unwinding

With 9 RPM motor, in 137.4 min, the mainspring gets fully wound. In one minute, 0.72% of the mainspring gets wound. Similarly, 100% of unwinding takes place in 2400 min. In one minute, 0.04% of the mainspring gets unwound. Hence, the Ratio is **0.72:0.04.** The winding ratio is 18 times higher than the unwinding ratio. Hence, the result validates the use of the 9 RPM synchronous motor for SEIKO 7S26A movement.

CITIZEN 8200A caliber

Identical to MIYOTA 8205, CITIZEN 8200A is a 21-jewel, 42-h automatic movement with day and date. It has a lift angle of 49° with 21,600 beats her hour. It uses yoke winding mechanism with Glucydur balance and pallet lever escapement. The movement can be wound either by manually rotating the crown or by the oscillating weight automatically. The rotor is unidirectional with its rotation restricted to counter-clockwise direction and it has become the key reason for choosing the caliber.

In CITIZEN 8200A movement, the Oscillating Weight, Pawl Winding Wheel, Reduction Wheel, Ratchet Wheel, the Click and Mainspring Barrel are constituted for winding the mainspring.

(1) Gear ratio of oscillating weight to ratchet wheel

The winding gear train of CITIZEN 8200A has Compound Gears. Hence,

$$\text{Gear Ratio is } \frac{\text{Product of tooth of driven}}{\text{Product of tooth of drivers}} \tag{3}$$

Let $\mathcal{OW}, \mathcal{PWW}$, and $\mathcal{RDW}, \mathcal{RW}$ denote the Oscillating Weight, Pawl Winding Wheel, Reduction Wheel and Ratchet Wheel, respectively. The following four Gear Ratios are calculated using the basic specifications of CITIZEN 8200A and Eq. (3).

Table 2 Gear ratio values

Gear ratio	Driver gear	Driven gear	Ratio value
$\Re_1$	$\mathcal{OW}$	$\mathcal{PWW}$	1:2.58
$\Re_2$	$\mathcal{PWW}$	$\mathcal{R}DW$	9:1
$\Re_3$	$\mathcal{R}DW$	$\mathcal{RW}$	5:1
$\Re_4$	$\mathcal{OW}$	$\mathcal{RW}$	116.47:1

From Table 2, the gear ratio of the oscillating weight to ratchet wheel is found to be 116.47:1. The Power Reserve of the caliber is 42 h [17].

(2) Time taken to wind a completely unwound main spring

The mainspring of CITIZEN 8200A is fully wound by 7.5 rotations of the Ratchet Wheel [17].

No. of turns of the rotor to completely wind the mainspring = $116.47 \times 7.5 = 873.5$

Winding speed (RPM) = 9

$$\text{Total Time Taken} = \frac{873.5}{\text{RPM} \times 60}$$

The total time taken is 1.61 h.

(3) Time taken to unwind a completely wound main spring

From the manufacturer's (CITIZEN 8200A caliber) claim, the time taken to unwind a completely wound mainspring (power reserve) is 42 h [17]. Therefore in 1 min, 0.03% of the mainspring gets unwound.

(4) Ratio between winding and unwinding

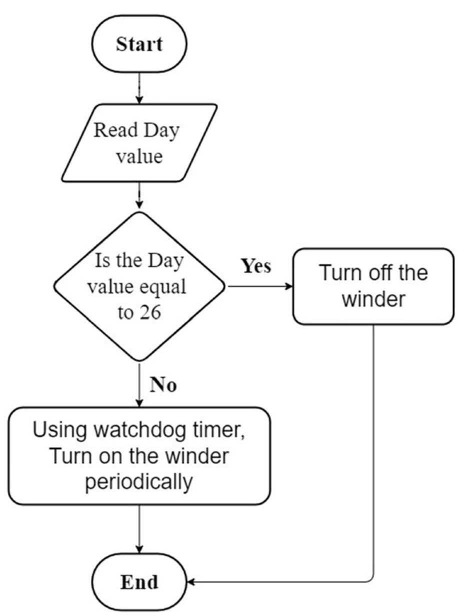

Fig. 3 Flowchart for fundamental decision making in the winder

With 9 RPM motor, 100% winding of mainspring takes 96.6 min. In one minute, 1.03% of the mainspring gets wound. Similarly, 100% of unwinding takes place in 2520 min. In one minute, 0.03% of the mainspring gets unwound. The ratio of the winding and unwinding is **1.03:0.03**. The winding ratio is 34.3 times higher than the unwinding ratio. Hence, the result validates the use of 9 RPM synchronous motor for CITIZEN 8200A caliber as well.

Validation for 60% winding rule

A mechanical or mechanical-self-winding watch requires a minimum of 15% winding of the mainspring to maintain the accuracy of time and to have an undisturbed run. So, a fully unwound caliber is not placed in the winder in still condition. The watch is usually pre-wound to 15% and the right time is set in the caliber before it is placed in the winder. So, setting 15% as the threshold, with which the caliber is placed in the winder, the proposed winder winds the mainspring by 60%. With the threshold of 15%, 75% of the mainspring is wound in total. This is sufficient to power caliber for 24 h. Let $W, UW, BMandWP$ denote the winding, unwinding, bare minimum and winding percentage, respectively. Then, the winding percentage for each day is calculated using Eqs. (4) and (5).

$$W_0 = (BM + WP) \tag{4}$$

$$W_{i+1} = (W_i - \mathrm{UW}_i) + \mathrm{WP} \text{ where } i = 0, 1, \ldots 26 \tag{5}$$

After 24 h, the caliber with 40-h power reserve is still in beat with 17.4%. Hence, it is evident to wind the caliber after 24 h with an implication that the daily working time of the winder is reduced by 40%. For consecutive days, there is an increment of 2.4% in the winding and the remaining percentage. The values are set in the winder to work for 25 days before its scheduled 1440 min break. As the 60% winding rule proves to be effective with 40-h power reserve, this rule extents to work good for all movements with higher power reserves.

Attiny85 and the watchdog timer

Known for the efficient and minimal power consumption, Attiny85 consumes ~ 2 mA at 1 MHz clock speed with 5 V input. Furthermore, it works with power consumption as low as 5uA in sleep mode. The watchdog timer interrupt wakes up the Attiny85 from the sleep mode. The maximum time between the consecutive interrupts is ob100001 (sleep bit pattern) which is equal to 8 s. But this sleep time is significantly insufficient. Hence, longer sleep time is achieved by recursively calling the 8-s interrupt until required.

Figure 3 shows a flowchart representing the fundamental decision-making sequence in the winder. Based on this decision, periodicity of working is defined using the algorithm given below.

Algorithm 1: Working Time and Sleep Time Evaluation

Input: Direction of rotation (CW/CCW), Total turns of Oscillating Weight (n)

Output: Working time and Sleep time of the Winder

```
1) Turn off ADC converter
2) Preset All Signal to LOW
3) Initialize Day = 0
4) If Direction == CW
5)        While (Day != 26):
6)                Send HIGH signal to Relay
7)                Enable watchdog timer for 8 seconds, ((4.5*n)/9) times
8)                Send LOW signal to Relay
9)                Enable watchdog timer for 8 seconds, (10800-((4.5*n)/9)) times
10)               Increment Day += 1
11)       End While
12)       Enable watchdog timer for 8 seconds, 1800 times
13)       Initialize Day = 0
14)       End if
15)       If Direction == CCW
16)               Send HIGH signal to Relay
17)               Send LOW signal to Relay
18)               GOTO Step 5
19)       End if
20)       End
```

System design

The model uses Attiny85 20SU SMD Microcontroller. It is programmed using the Arduino development board [18] and it is designed to stay in the sleep mode for maximum time. The setup is fabricated on PCB with the microcontroller, 5-V Single Pole Double Throw relay, an NPN transistor to drive the relay, a fly-back diode to curb the back emf developed during the coil's switching and a base resistor to limit the current which is flowing though the base. A 220 V Single-phase AC Synchronous motor is externally wired to the printed circuit board. The synchronous motor changes its direction of rotation for every odd switching. Figure 4 shows the circuit diagram of the proposed winder.

Figure 5 depiction is the 2-layer PCB layout of the winder designed with KiCad [19, 20].

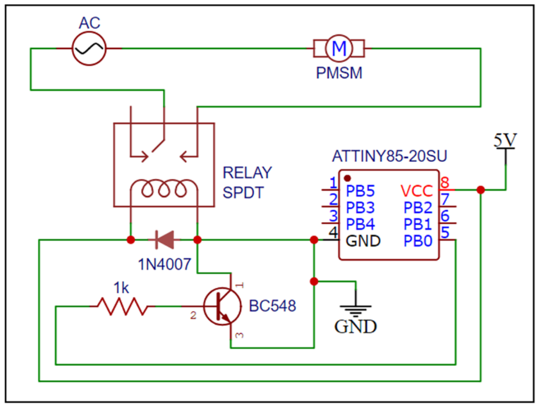

Fig. 4 Circuit diagram of the proposed winder

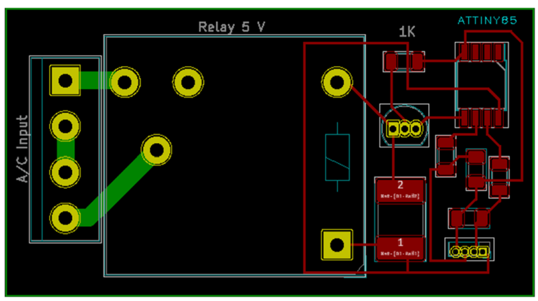

Fig. 5 PCB Layout

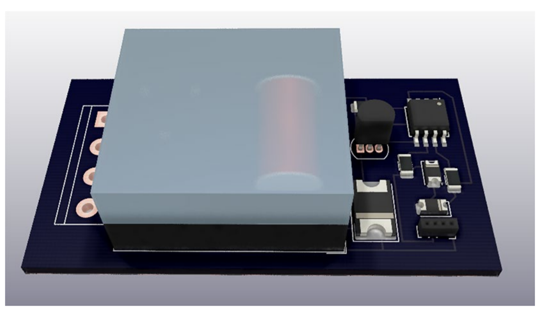

Fig. 6 3-Dimentional view of the PCB

Figure 6 portrays the 3-D rendered image of the proposed winder. The DC input is connected using male–female jumper cables while the mains current for synchronous motor is directly soldered to the board. To the shaft of the synchronous motor, an enclosure in which the watch is placed is coupled about an axis perpendicular to the axis of the shaft. During scheduled intervals, the relay switches the motor and the shaft along with the enclosure and watch rotates thereby winding the mainspring of the caliber.

The prototype of the model is made using a 9 RPM single-phase Synchronous motor, Attiny85 module and 5-V single-pole double-throw relay module. The watch is fixed intact on the base and the base is screwed directly to the shaft of the motor. Figure 7 depicts the prototype of the model.

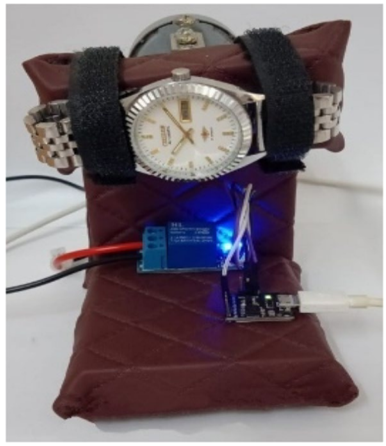

Fig. 7 Prototype of the proposed winder

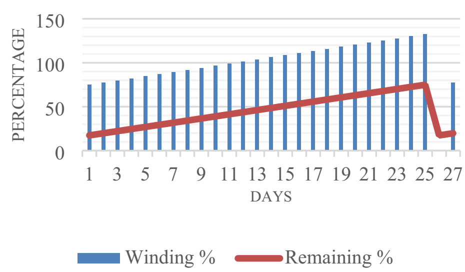

Fig. 8 Percentage of the winding and remaining ratios for 27 days

Results

System time frame

Figure 8 noticeably highlights the recurrence of winding percentage 17.4 on the 27th day if the winder is suspended from run on the 26th day. Hence from Fig. 8, a 25-day cycle is formulated. Though the proposed winder works to wind only 60%, it takes a 24-h break every month, while the commercial winders work round the clock.

Figure 9 clearly picturizes that the 60% winding rule pays off for all calibers with power reserves 40 h or higher depicted as in Tables 3 and 4.

Working hours of the proposed model versus the commercial model

Table 5 compares the working hours of the proposed winder to that of the market-available models. The proposed model in all cases winds the mainspring only by 60% while the commercial models carry out 100% winding superfluously.

Figure 10 depicts the total working hours of the proposed model and the commercial models. It is evident from Fig. 10 that the working time of the proposed winder is significantly less. Hence, the model decreases the unnecessary working time and thereby it increases the efficiency of the winder.

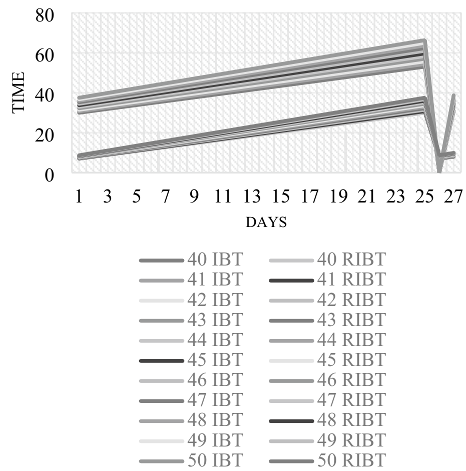

Fig. 9 In beat time and remaining in beat time for power reserves between 40 and 50

Table 3 In beat time and remaining in beat time for power reserves 40 and 41

Day	40 h power reserve		41 h power reserve	
	IBT	RIBT	IBT	RIBT
1	30	6.96	30.75	7.134
2	30.96	7.92	31.734	8.118
3	31.92	8.88	32.718	9.102
4	32.88	9.84	33.702	10.086
5	33.84	10.8	34.686	11.07
25	53.04	30	54.366	30.75
26	0	6.96	0	7.134
27	30.96	7.92	30.96	8.118

Table 4 In beat time and remaining in beat time for power reserves 49 and 50

Day	49 h power reserve		50 h power reserve	
	IBT	RIBT	IBT	RIBT
1	36.75	8.526	37.5	8.7
2	37.926	9.702	38.7	9.9
3	39.102	10.878	39.9	11.1
4	40.278	12.054	41.1	12.3
5	41.454	13.23	42.3	13.5
25	64.974	36.75	66.3	37.5
26	0	8.526	0	8.7
27	37.926	9.702	38.7	9.9

Conclusions

With the proposed tourbillon watch winder, the winding period for the Seiko and Citizen calibers are reduced by 29.89 h and 21.11 h respectively. Hence, the proposed model is proven to work efficiently with the 60% winding rule for all self-winding calibers with 40-h or higher power reserves. As a future work, the disclosed algorithm can be further

Table 5 Comparison of working hours of the proposed and commercial winders

Total working hours	Proposed model		Commercial model	
	Seiko	Citizen	Seiko	Citizen
1 day	1.37	0.96	2.29	1.61
7 days	9.59	6.72	16.03	9.66
31 days	41.1	28.8	70.99	49.91

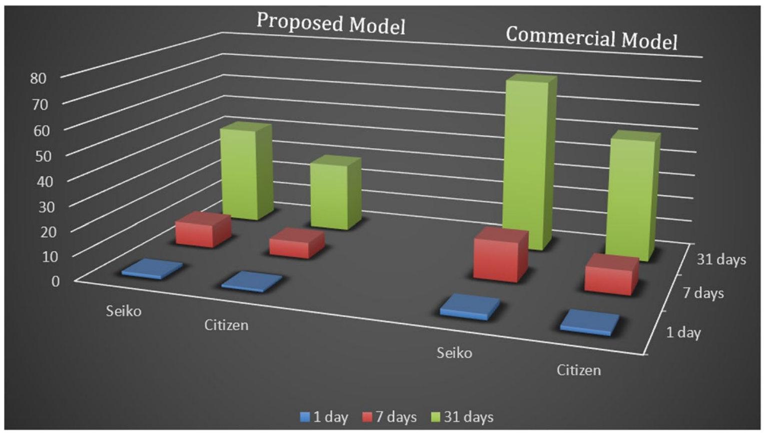

Fig. 10 Working hours of winders

modified to provide timed-intervals for the synchronous motor to cool down. The model can be enclosed in a honey-comb structured container which not only has a high strength-to-weight ratio, but also possesses good shock absorbing capacity.

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Author contributions
The full-length research has been carried by single author who is the Corresponding Author (Madhavan Thothadri). The author read and approved the final manuscript.

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Consent for publication
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References

1. Agnoff C (2003) Oscillating watch winder. US Patent 6,543,929 B1, Apr. 8, 2003

2. Gu Xu, Ko PH, Du R (2011) A study on the precision of mechanical watch movement with Tourbillon. J Sound Vib 330(16):4019–4028. https://doi.org/10.1016/j.jsv.2011.03.020
3. Aihara T, Kamio C, Hara Y, Ito K, Jujo K (2021) Dynamic accuracy measurement system for mechanical wristwatch. Precis Eng 70:117–123. https://doi.org/10.1016/j.precisioneng.2021.01.018
4. Singh GP (2014) Designing of a microcontroller based multi-sensor system. Thesis, National Institute of Technology, Rourkela
5. Circuit Globe. Effect of load on a synchronous motor. https://circuitglobe.com/effect-of-load-on-synchronous-motor.html. Accessed May 3, 2021
6. Matsuoka K (2007) Development trend of the permanent magnet synchronous motor for railway traction. IEEJ Trans Elec Electron Eng 2:154–161. https://doi.org/10.1002/tee.20121
7. Shi Z, Zhang P, Lin J, Ding H (2021) Permanent magnet synchronous motor speed control based on improved active disturbance rejection control. Actuators 10:147. https://doi.org/10.3390/act10070147
8. Sun X, Cai F, Yang Z, Tian X (2022) Finite position control of interior permanent magnet synchronous motors at low speed. IEEE Trans Power Electron 37(7):7729–7738. https://doi.org/10.1109/TPEL.2022.3146841
9. Sun X, Cao J, Lei G, Guo Y, Zhu J (2020) Speed sensorless control for permanent magnet synchronous motors based on finite position set. IEEE Trans Ind Electron 67(7):6089–6100. https://doi.org/10.1109/TIE.2019.2947875
10. Singh B, Sharma J (2017) A review on distributed generation planning. Renew Sustain Energy Rev 76:529–544
11. Patel DK, Singh D, Singh B (2021) A survey on impact assessment of distributed generations and electric vehicles in distribution systems. J Energy Stor Elsvier (SCIE) 43(3):24–42. https://doi.org/10.1002/2050-7038.12576
12. Patel DK, Singh D, Singh B (2020) GA-based multi-objective optimization for distributed generations planning in distribution systems with ZIP load models. Int Trans Electr Energy Syst J (SCIE) 1(3):22–43. https://doi.org/10.1002/2050-7038.12576
13. Wuntch T, 10638 Boedeker St., Dallas, Tex. 75230 (1977). WATCH WINDER US Patent 4,057,958, Nov. 15, 1977.
14. Agnoff C (2007) Tourbillon watch winder. US Patent 7,270,474 B2, Sep. 18, 2007
15. Wolf VSP, Malibu CA (US), Tony Ming Sanging, Kowloon (HK) (2009) Controllable watch winder for self-winding watches. US Patent 7,575,367 B2, Aug. 18, 2009
16. Hacko N (2021) The oscillator and the gear train. http://www.clockmaker.com.au/diy_seiko_7s26/chapter9.html. Accessed April 17, 2021.
17. Miyota 8205 User manual. https://www.watch-tools.de/media/import/howto/0960blen.pdf. Accessed April 22, 2021
18. Alaspuresujay (2019) Use an ATtiny85 with Arduino IDE. https://create.arduino.cc/projecthub/alaspuresujay/use-an-attiny85-with-arduino-ide-07740c. Accessed April 03, 2021
19. Component Search (2017) Attiny85 Footprint and datasheet. https://componentsearchengine.com/part-view/ATTINY85-20SU/Microchip. Accessed May 15, 2020
20. Kicad Software. http://kicad.org/download/ Accessed May 10, 2020

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