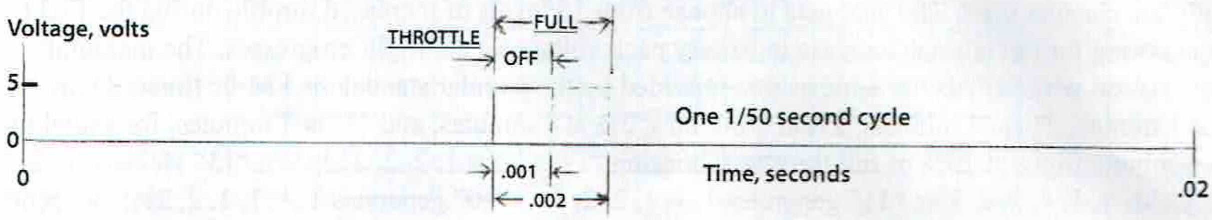
The FM-9 Motor Control System

Introduction

Electric power for models has built on the early experience with gas- and glow-powered engines. The throttle channel on an **R/C** (Radio Control) model drives a servo which moves a rod mechanically connected to the engine's throttle lever. Thus the throttle channel of an R/C receiver outputs the same servo signal for both the throttle and the flight controls. The typical servo signal is a **pulsed** 5-volt signal that is repeated about **50 times** a second (frequency of **50 Hz**). The time that the signal stays at 5 volts during each 1/50 second is known as the **pulse width**. This pulse width or duration must vary between about 1 millisecond (.001 second) and 2 milliseconds (.002 second), which corresponds to the range of a servo from minimum to maximum – and, when driving a throttle, between throttle-**off** to **full** throttle.

So even though electric motors are driven by a **direct** voltage, to be compatible the electronic speed controls (ESC) were designed to use the same 5-volt servo signal from the throttle channel to **instruct** the ESC to send a generally much higher voltage and provide much higher currents to an electric motor. (For a **brushless** motor, now the most common type, the voltage must be applied to the poles in just the right sequence and with just the right timing to send the shaft rotating in the desired direction; this sequencing frequency is known as pulse width modulation frequency or **PWM** frequency, because the duration of the voltage to the poles determines the power generated.)

Almost all ESCs require a **throttle-off** (1 ms pulse width) when **first** powered-up **before** they will even **start** to turn the motor shaft—an important safety feature. (The alternative, usually used to program the ESC for different properties or features, is to power up with a full throttle [2 ms pulse width] and then to use specified excursions to throttle-off to turn on or turn off certain features of the ESC such as braking. But then the power has to be removed and the standard throttle-off sequence used to run the motor.)



The FM-9 System

The FM-9 series of "timers" (or, better, electronic flight managers) generates this required range of 5-volt pulses, starting with 1 ms (throttle off), upon power-on, to convince an ESC that it is a legitimate source of throttle signals. Many ESCs, when first powered up, will generate beeps that indicate how many cells it detects in the LiPo battery pack. Following these, the ESC typically generates a different sound sequence if it recognizes a throttle-off signal. If you don't hear this second sound, you know that the timer is either not connected properly or has passed away.

The connection between an ESC and a timer uses the same 3-wire cable that can be plugged into the throttle channel of an R/C receiver in only one way, but it can be connected **incorrectly** to a timer. The center wire and one outer wire (the ground wire, black or brown in color) carries the power to the timer. The other outer wire is the signal wire through which the timer sends throttle pulses to the ESC. These are generated by the embedded computer chip (*microcontroller*) on the timer. The microcontroller has **no way** of knowing if it is connected to anything, let alone if it is signaling an ESC or whether the motor is overheating or otherwise unhappy. Your hope is that the ESC will recognize any excessive current draw or reduced battery pack voltage and shut down the motor before the end of the flight time and when the timer does the job. However, if you can get to an FM-9 timer very quickly, you can **always** stop the motor during the flight time by pressing the **start button**.

The first ESCs assumed that the R/C receiver was already powered by its own battery of around 5 volts and the ESC could concentrate on using the much higher voltage (and current capability) from the flight battery to power the motor. But this required two batteries in the airplane and so manufacturers began adding a battery elimination circuit (**BEC**) to their ESC. This voltage regulator circuit had the unpleasant task of reducing some very high battery pack voltages to 5 volts. The first BEC circuits used a built-in **linear** voltage regulator circuit which is inefficient, generating heat proportional to the voltage difference. This is not a problem for an FM-9 timer because it requires only a tiny amount of current from the 5 volt supply—but a real problem for an R/C airplane with many servos and potentially for control-line (**CL**) airplanes using servos to retract the gear. So many manufacturers have turned to a built-in **switching** voltage regulator circuit which is more efficient. Another approach, when high BEC currents are required, is to use a separate external BEC—but it is still current-limited as the battery pack voltage goes up.

The FM-9 Timer

The FM-9 Programmer box takes advantage of the FM-9 timer's microcontroller chip's non-volatile memory to program the timer for three basic modes: (**1**) **Constant throttle output** along with a programmable delay time (to allow the user to get to the center of the circle and pick up the handle without wasting battery charge) and for a programmable flight time. (**2**) **Compensated throttle output** with a programmable delay time and flight time. This is the recommended mode if you are using an ESC that does **not** offer a governed mode – usually the cheaper ones. The user gets to choose from 15 levels of increased throttle during the flight, compensating for the normal decrease in battery pack voltage as the flight progresses. The maximum compensation with "15" is the same as that provided by the popular standalone FM-0c timer: 2% at 30 seconds, 2% at 1 minute, 2% at 2 minutes, 2% at 3 minutes, 2% at 4 minutes, and 3% at 5 minutes, for a total increment on a 6-minute flight of 13% of full throttle. Choosing "14" yields 1, 2, 2, 2, 2, 3%; "13" yields 1, 2, 2, 2, 2, 2%; "12" yields 1, 1, 2, 2, 2, 2%; "11" generates 1, 1, 1, 2, 2, 2%; "10" generates 1, 1, 1, 1, 2, 2%; "9" generates 1, 1, 1, 1, 1, 2%; "8" generates 1, 1, 1, 1, 1, 1%; "7" generates 0, 1, 1, 1, 1, 1%; "6" generates 0, 0, 1, 1, 1, 1%; "5" generates 0, 0, 0, 1, 1, 1%; "4" generates 0, 0, 0, 0, 1, 1%; "3" generates 1, 0, 0, 0, 0, 1%; "2" generates 1, 0, 0, 0, 0, 0%; "1" generates 0, 0, 0, 0, 0, 1%; "0" makes no increase in throttle during the flight. (**3**) **RPM-based throttle output** to an ESC that promises to keep the RPM constant (or **governed**) by increasing the current as necessary as the battery pack voltage decreases – as long as the voltage doesn't decrease too much and so long as the chosen RPM gives it enough headroom below the no-load maximum RPM for the battery-motor combination. See below.

The cell voltage of a LiPo battery pack decreases to 3.7 volts under moderate load so a 4-cell LiPo battery pack and a motor with a **kV** of 920 RPMs per volt would have a theoretical no-load maximum RPM of (4 x 3.7 volts) x (920 RPM / volt) = 13,616 RPM and you should normally aim for an RPM of about 75% of this, or around 10,200 RPM. (Usefully Castle Creations Castle Link program suggests that its ESCs could govern the RPM between about 8580 RPM up to about 11,600 RPM, with these parameters.)

I have used a test stand to determine the resulting RPMs through a range of throttle inputs, at intervals of 5% of maximum throttle throughout the usable RPM range for a number of these ESCs that promise to govern the RPM. They apply only for a **14-pole motor** but you can assume that a 12-pole motor, for example, will generate an RPM about 12/14 times the displayed RPM, etc. The FM-9 Programmer contains tables of all these measured RPMs versus throttle data. The embedded program then interpolates between these data points to allow you choose RPMs at increments of only ½ of 1% of full throttle! So when you select an RPM, the Programmer looks up the corresponding throttle value and that is what it gives the FM-9 timer. (If curious, you can switch momentarily to the throttle mode and see what throttle value it came up with.)

But the only really important consideration is what displayed RPM flies your airplane as you wish and the fact that you can return to it every time, with digital precision, flight after flight.

<u>The Governed RPM modes</u>

A. **Brodak Hornet mode.** The Hornet ESC supports two- to six-cell LiPo battery packs, promises a maximum current output of 40 amperes, and provides up to 4 amperes from its BEC. The listed RPMs are from 7,200 to 11,820. The Hornet ESC is available from Brodak at **www.Brodak.com** as **BH-1866**.
B. **Phoenix Set RPM mode**. Using a Castle Creations cable (Castle Link) from one of their ESCs to a USB input on a PC and with their free PC program, you can choose **Airplane → Control Line → Set RPM**. When you choose this mode you can also specify the kV of your motor and the number of LiPo cells in your battery and then it will tell you if any of three RPMs that you choose are within the governed or constant-RPM limits. For example, when I chose a motor with a kV of 920 and a 4S battery (4 LiPo cells) and 1:1 gearing between the motor and the prop, and tried different RPMs, it told me that the range of usable RPMs was 8580 at the very bottom to 11,600 RPM at the very top.
    a. In flight, RPM #1 is used if the throttle is less than about 50%, RPM #2 is used if the throttle is somewhat over 50%, and RPM #3 is used for a full throttle input. When you choose this Set RPM mode with the FM-9 Programmer, it makes it easy for you because you just need to choose which of the three RPMs you want to use and the Programmer sends the appropriate throttle value to the FM-9 timer.
    b. For the one second end-of-flight warning, the FM-9 timer chooses RPM #3 if you use RPM #1 for the flight time and RPM #1 if you use RPM #3 for the flight time.
    c. One disadvantage of the Set RPM mode is that you can't choose any other RPMs without connecting to a PC and using Castle Link, although a laptop at the field would work. But once you've figured out which RPMs fly your airplane at three different field or wind conditions, this mode works well. Additionally, it gives you accurate RPMs for motors with other than 14 poles.
C. Schulze F2B Low. The Schulze F2B was designed for F2B Stunt along with an Orbit motor and was a pioneer in constant-RPM/governed RPM controllers. It does require an external BEC.
D. Jeti Spin. This ESC is common in Europe and can be programmed for the governed mode. The calibration is old and may not be current with the latest ESCs.
E. Hacker High X30. This is a German ESC, also not very common in the U.S. It also must be programmed into the governed mode.

F. Phoenix ICE/EDGE. Castle Creations produces or has produced the Phoenix ICE, the Phoenix Edge, and the Talon, which can be programmed with a PC and **Castle Link** for these ESCs, as follows: **Airplane → Control Line →Governed High**. This has been a popular mode and allows the user to adjust the RPMs in the finest increments of change, through ½ of 1% of throttle increments.

a. For a new model, one can choose flight times of 1 minute or so and make adjustments of trim and RPM between flights to quickly arrive at a good-flying combination. The Castle PC program also allows the user to make many other adjustments to ESC parameters such as motor timing and braking. A good guide is provided by Norman Whittle's "Cookbook for the AXI 2826/12 and Castle ICE 50 Lite & FM-9 Series of Timers" (available on the internet).

b. The "Governed Low" mode may be useful for low-pole motors or where the desired RPMs are much lower than usual. Use the throttle mode to access them and establish your own calibration. Also, the Set RPM mode is a good choice with low-pole motors.

Basic FM-9 Timers

The FM-9 has the start button on the timer board and so can be used on profile-fuselage models in which the timer can be mounted on the side of the fuselage within easy reach. The FM-9rem has the start button at the end of a 6" long cable, so the timer can be mounted inside the fuselage and the start button on the outside. Even though you can always stop the signal to the ESC by pushing the start button during the flight time, for extra safety and for competition, a separate shut-off for the battery is necessary (e.g., ArmSafe by SharpRC).