

The Model T E-Timer

Electronic Timer with Automatic Timing Advance and Much More

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Electro-Mechanical Marvel

The merits of the original Model T ignition system are well known and well documented^{1,2}. The simplicity of design and sheer elegant implementation is a true electro-mechanical marvel that has served its purpose well for the past 100 years and is worthy of preservation for future automotive enthusiasts. It is fortunate there are individuals who possess the knowledge, skills, components and tools necessary for proper installation, adjustment, operation and maintenance of the original ignition system and are satisfied with the resulting performance. Unfortunately for many, the original ignition system often presents a formidable obstacle to enjoying their car to the fullest. To appreciate what it takes to achieve optimum performance requires a review of the ignition system components and variables that must all function together. Just like musicians in an orchestra, a single mistuned component can seriously degrade the overall experience. Here is a fairly detailed list of ignition system components and associated variables that must all function in concert.

Ignition System Components and Variables

1. Battery

- a. Voltage
- b. Current capacity
- c. Terminal contacts

2. Magneto

- a. Voltage output
- b. Current capacity
- c. Magnet strength and consistency
- d. Magnet integrity; cracks
- e. Coil integrity, resistance

- f. Magnet to coil spacing
- g. Magnet to coil concentricity
- h. Magnet to coil co-planarity
- i. Electrical terminal contact

3. Spark Plugs

- a. Gap
- b. Insulation
- c. Contamination, carbon
- d. Plug wire electrical contact

4. Spark Plug Wires

- a. Wire resistance
- b. Wire insulation
- c. Electrical terminal connections

5. Coil Box

- a. Coil unit fit, alignment, movement; electrical contact.
- b. Coil unit contact spring tension; contact resistance
- c. Coil box wood insulation resistance; high voltage leakage, arcing
- d. Coil box internal wiring; battery, magneto
- e. Coil box insulator integrity
- f. Electrical terminals; tight, clean

6. Coil Box Wires

- a. Wire resistance
- b. Wire insulation
- c. Electrical terminal connections

7. Coil units

- a. Points
 - i. Contact resistance
 - ii. Spacing; Alignment
 - iii. Vibrator tension
 - iv. Cushion spring tension
 - v. Capacitor(condenser) integrity; open, short
- b. Coil primary winding integrity; inductance, resistance

- c. Coil secondary winding integrity; inductance, resistance
- d. Primary to secondary isolation
- e. Primary and Secondary to core isolation
- f. Wood insulation resistance; high voltage leakage

8. Timer

- a. **Timer/roller contact resistance, bounce**
- b. **Timer contact concentricity**
- c. **Timer internal insulator concentricity, consistency**
- d. **Roller spring tension**
- e. **Roller contact resistance**
- f. **Roller concentricity; smoothness**
- g. Pull rod adjustment range
- h. Terminal insulator integrity
- i. Electrical terminal contacts

9. Operator Control

- a. **Proper adjustment of spark lever and spark timing with engine RPM**

Originality Versus Performance

There have been numerous attempts to improve or eliminate many of the Model T ignition variables over the years with the goal of simplifying operation, reducing maintenance and improving performance. A modern electronic ignition system that's easy to install, requires no maintenance and is unconstrained by the mechanical limitations of the original ignition system would seem the ultimate goal but is only attractive for a classic automobile if its existence does not destroy originality, appearance or function of the automobile. This article describes just such a system under development with emphasis on eliminating many of the problematic elements of the original ignition system highlighted in blue that are costly to repair, require specialized skills, knowledge or tools. Keep in mind that the remaining variables not highlighted must still be properly addressed if the system is to operate properly. Fortunately, most of those

remaining variables are well within the capability of the average person like clean, tight, electrical connections and properly gapped, clean spark plugs.

A summary of objectives for the Model T electronic ignition system are:

- **Eliminate Consumable Elements**
 - Points
 - Timer contacts/rotor/brushes
- **Retain Originality**
 - No modifications to the car
 - Use the original coils
 - Coils still vibrate and buzz
 - Use the original wiring
 - Operate on 6, 8, 10, or 12V
 - No adjustments
 - Easy to restore back to all original
- **Simple Battery Operation**
 - Eliminates magneto variables
 - Solution for non-functioning mag
- **Superior Performance**
 - More precise engine timing
 - Automatic timing advance
 - Smooth, efficient operation
- **User Programmable Timing**
 - Automatic timing mode
 - Original Model T timing mode

The Approach

An imperceptible implementation vastly complicates the design choices. The obvious location to conceal the control electronics is the limited space within the timer housing making it an Electronic Timer or **E-Timer**. A review of what it takes to perform the electronic ignition function provides a better appreciation of the packaging challenge that had to be overcome.

The basic approach is identical to the well known electronic ignition systems of modern cars: replace the roller with a magnetic actuator fixed to the CAM shaft and use Hall sensors to detect CAM shaft position. Then replace the timer contacts with their modern solid state equivalent; Insulated Gate Bipolar Transistor (IGBT) switches that can fire the original coils when triggered by the respective

Hall sensor. The coil points are no longer necessary and are bypassed (shorted) with a small wire jumper.

Understanding how the E-Timer functions is simplified by a review of the original Model T ignition system operation. Recall the elegance of the original roller/timer contact ignition system. The roller simply grounds the primary of the proper coil at the proper time as the roller rotates on the CAM shaft. Once the coil primary is grounded by the roller/contact, current flows through the closed points creating a magnetic field in the coil primary until the field becomes strong enough to pull open the points creating the spark. This process guarantees the current in the coil primary is high enough to produce a good spark yet is self limiting to ensure the current does not get strong enough to cause overheating and damage to the coil primary provided the points are properly adjusted.

The E-Timer could mimic this behavior but that would require considerable circuit complexity to monitor each individual coil primary current. Fortunately there is another method of charging the coil that is as effective without having to measure the current of each coil and thus consumes much less space. It turns out that the current in the coil rises at a constant rate with time according to the formula:

$$\Delta i / \Delta t = V / L \quad \text{Eq. 1}$$

Equation 1 says the change in coil current, Δi divided by the change in time, Δt , is equal to the battery voltage, V , applied to the coil divided by the inductance of the coil, L . Coil inductance is determined by the number of turns of wire used to wind the coil. So we can determine the change in coil primary current, Δi by knowing the battery voltage, V , the coil primary inductance, L and how long we let the coil to charge, Δt .

$$\Delta i = V * \Delta t / L \quad \text{Eq. 2}$$

The only caveat is each coil must be similar (same L value) so the rate of charge is the

same for all coils which they typically are. The typical coil charge time for a model T coil operating from 12V is 1.8ms¹. The typical coil inductance, L , is 3.3mH (0.0033H) so the corresponding coil current is approximately:

$$12 * 0.0018 / 0.0033 = 6.5A \quad \text{Eq. 3}$$

That may seem like a lot of current but remember, it only lasts for 0.0018 seconds before being turned off when the coil fires.

Command and Control

The E-Timer utilizes a miniature computer known as a microcontroller with self contained memory used to store programming instructions that determine how it functions. Software instructions were written to read CAM shaft position sensors, battery voltage, engine temperature and calculate the ignition timing delay depending upon engine RPM. The software instructions are coded in the C programming language and total more than 1500 lines.

CAM Sensing

Four separate IGBTs are used to fire each ignition coil independently. Several methods were tried to determine the best way to sense CAM position and time firing of the coils. It was determined that the best method was to separate CAM position sensing and ignition timing by using independent sensors³. CAM position sensing is accomplished by two magnetic Hall sensors placed on the E-Timer circuit board placed at 90 degree angles to one another. A CAM shaft magnetic actuator is affixed to the CAM with 2 magnets also positioned 90 degrees apart to provide the capability of sensing the CAM shaft cylinder firing positions as illustrated in Figure1.

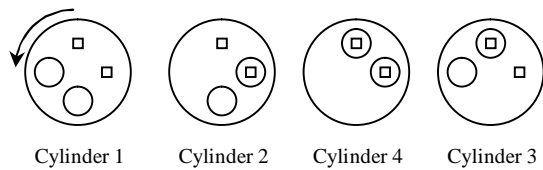


Figure 1 CAM Position Sensing

The preferred way to utilize Hall sensors for precision timing applications is to use a single fixed Hall sensor and a single fixed magnet separated by a small gap. This eliminates sensor to sensor and magnet to magnet variations. A ferrous vane with four windows machined in it is affixed to the CAM shaft to actuate the Hall sensor when a piston is in firing position. The precision of the timing is now a function of the vane window dimensions and tolerances and is immune to variations in concentricity and CAM shaft or radial end play. That's why the vane method was utilized in electronic distributors. Figure 2 illustrates the CAM vane actuator with timing windows for each cylinder.

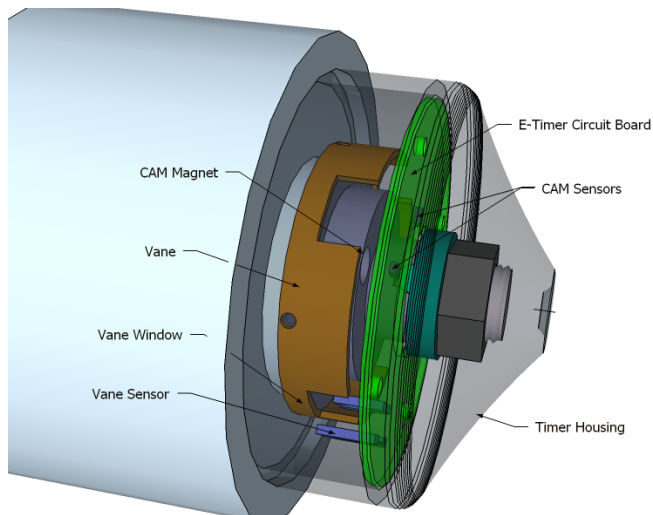


Figure 2 Ferrous Vane Actuator

Design Verification

The E-Timer performs complex timing of 4 ignition coils that is difficult to capture on standard electronic instruments such as an oscilloscope which typically only permits monitoring of 2 simultaneous activities. A

custom test set was designed and built that emulates engine CAM shaft operation while monitoring CAM shaft position and the firing of all 4 E-Timer coils electronically. Figure 3 illustrates the CAD model used to design and build the final E-Timer test set.

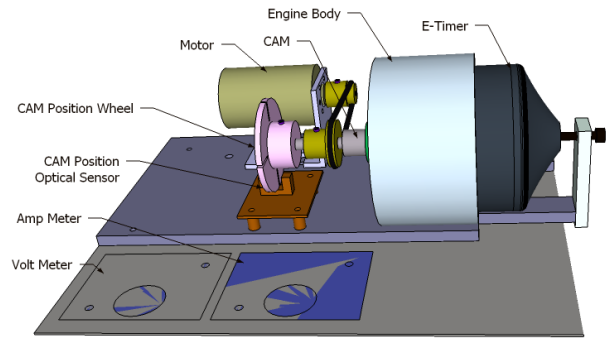


Figure 3 E-Timer Test Set CAD Model

The test set consists of an engine body used to mount the E-Timer similar to the actual engine mounting. An electric motor drives the CAM shaft via cogged drive belt and pulleys. The CAM shaft is fitted with a position indicator wheel that has 4 slits in it used to sense positions of cylinders 1, 2, 3, and 4 at Top Dead Center (TDC) by an optical sensor. The test set employs a microcontroller that monitors the CAM position optical sensor and E-Timer coil terminals to determine when each coil fires with respect to the CAM position sensor. The data is then transferred to a laptop PC for display and analysis. The actual E-timer test set that was built and perfected to characterize E-Timer performance is illustrated in Figure 4. An E-Timer is fully tested and characterized before installation and field testing on a car.

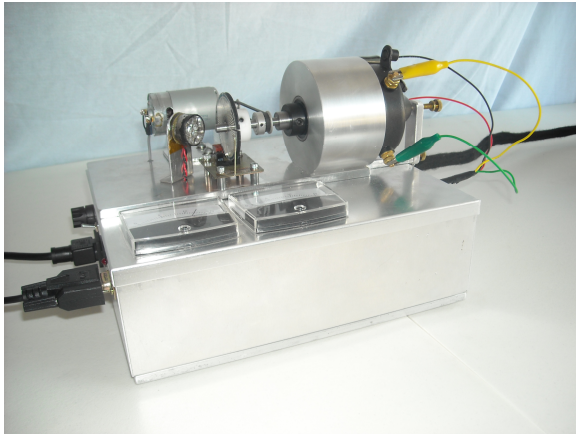


Figure 4 E-Timer Test Set

The E-Timer test set is capable of monitoring the firing of each coil in respect to the CAM position with resolution of 4 microseconds (0.000004s) or less than 0.25 degrees at 2000 RPM. E-Timer test results show that ignition timing variation between cylinders is typically 1 degree or less.

Installation

The E-Timer installs in place of the original timer without any changes to the car or its wiring making it very easy to revert back to all original operation whenever desired. Installation is very similar to an original timer with the magnetic vane actuator taking the place of the roller, brush or flapper depending upon which original timer it replaces.

The operator must verify proper timing lever operation and adjustment range before operation. This is an important safety step to avoid personal injury after installing any new timer on a Model T. The purpose is to ensure spark does not occur until the piston passes top dead center with the spark lever all the way up (fully retarded) so the engine does not kick back during cranking.

Starting the Engine

The engine starting procedure with the E-Timer is done the exact same way as the original Model T ignition system operating from battery. There is nothing new to learn. Set the spark lever all the way up (fully

retarded) prior to cranking the engine. Turn the ignition power to battery and crank the engine. Once the engine starts, advance the spark lever as necessary for optimum performance.

The coil points still vibrate and buzz just as they did originally, albeit a little more consistently. Free starts may also occur as usual if a piston is on its compression stroke when the ignition power it turned on.

Selectable Timing Modes

The E-Timer provides two, user selectable, modes of operation. Manual Timing (MT) mode that mimics original Model T operation where the operator is responsible for proper timing lever adjustment at all times and Automatic Timing Advance (ATA) mode where the E-Timer monitors engine RPM and automatically adjusts spark timing for optimal engine performance. ATA mode is the default timing mode.

Automatic Timing Advance Mode

Automatic Timing Advance (ATA) mode operation does not commence until the engine CAM has completed 125 consecutive revolutions. This gives the operator sufficient time to secure the crank and make their way to the driver's seat to advance the spark lever; about 30 seconds at 500 RPM. The spark lever is advanced to 45 degrees before Top Dead Center (TDC) and remains fixed during operation. The E-Timer computer monitors engine RPM and delays spark timing automatically so ignition always occurs at the optimum piston position as will be described shortly.

The initial delay in entering ATA mode is a safety feature that ensures no alteration of ignition timing during cranking. The E-Timer also exits ATA mode immediately when the engine stalls reverting back to MT mode for safe engine cranking.

How Automatic Timing Advance Works

Understanding how Automatic Timing Advance (ATA) mode functions is simplified by referencing to the chart of Figure 5. The

original Model T timing is the blue line shown with triangle markers on the bottom of the chart. Ignition timing starts at 15 degrees after TDC per Ford recommendations with the timing lever all the way up (Retarded). Timing continues to retard as the engine RPM increases. The reason for this is due to the fixed amount of time the coil needs to charge (1.8ms on 12VDC) before being fired. So the ignition timing (spark) is simply the number of degrees the crank shaft travels during this fixed 1.8ms delay while the coil is charging.

The faster the engine RPM, the more crank travel and the more retarded the timing for the same 1.8ms delay. Hence, the need to advance the blue timing curve upward by advancing the timing lever until timing advances before top dead center where the spark occurs. The spark must occur before top dead center because there is another short delay from when the spark occurs and when peak power (pressure) is delivered to the piston called ignition lag which is approximately 1.5ms.

The E-Timer can only add delay once it senses piston position from the CAM vane sensor. The technique used to implement Automatic Timing Advance is to advance the timing lever to 45 degrees before TDC and let the E-Timer microcontroller add delay to retard the spark as necessary to ensure the spark occurs at the correct point before the piston reaches TDC. The crank continues turning during the ignition lag delay so peak power (pressure) is delivered to the piston after the piston has passed TDC as desired.

The process steps are illustrated in Figure 5. Step 1: the timing lever is set fully retarded (all the way up) for starting the engine at 15 degrees after TDC per Ford recommendations. Step 2: Move the timing lever to advance the timing by 60 degrees; to 45 degrees before TDC after the engine starts. This shifts the blue ignition timing line up to the green line position which is too far advanced. Step 3: The E-timer adds delay depending upon engine RPM to delay ignition timing (spark) to occur on the red line. Step

4: Ignition lag of about 1.5ms occurs before peak power delivered to the piston. Step 5: The crank continues to turn during the ignition lag delay until peak power is delivered at TDC (0 degrees).

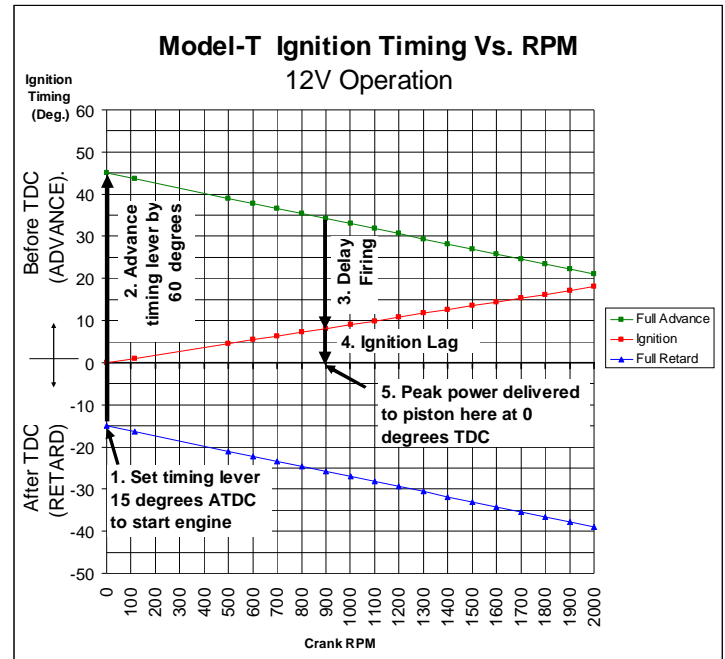


Figure 5 Model T Ignition Timing

Programmability 1909 Style

Some drivers may consider ATA mode undesirable because it changes functionality and deprives them of the full operating experience associated with controlling the timing lever. A method of programming the E-Timer timing mode was needed but how to do that was not obvious without having to add wires, switches or jumpers which would violate the originality constraint. The solution is quite novel. Have the microcontroller sense the presence of absence of coils installed in the coil box when the ignition switch is turned on to specify the default timing mode whenever it is turned on again.

For example, remove all coils from the coil box except coil 1 and turn on the ignition. The E-Timer knows you are not trying to operate the car on only 1 cylinder so it knows you are trying to tell it something; to set the default timing mode to Automatic Timing Advance mode whenever the E-Timer is powered up again with all coils installed as

usual. Alternately, remove all coils from the coil box except coil 2 and turn on the ignition to set the E-Timer default timing mode to Model T timing mode whenever it is powered up again with all coils installed. Removing coils to program the timing mode may seem a bit crude but it solved the problem of providing user programmability without sacrificing the originality of the Model T. Once set, the default timing mode may seldom need change.

What About 6V Operation?

A fair number of Model T owners operate their Model T from 6V DC. I've also heard reports of operation on 8V and 10V in addition to 12V. So a more universal solution was needed. The E-Timer can be powered from 6, 8, 10 and 12 VDC by changing the coil charge time. Recall the coils are charged for a fixed amount of time as opposed to sensing the charge current level to determine when they are fully charged and ready to fire. Recall the coil current is:

$$\Delta i = V * \Delta t / L$$

Halving the voltage, V, from 12 to 6 while keeping the same charge time, Δt , and coil primary inductance, L, reduces the coil current by half (from 6.5A to 3.25A). That results in a pretty weak spark that may be unacceptable especially on a fouled spark plug. But if we double the coil charge time from 1.8ms to 3.6ms when operating from 6V DC we can charge the coil to the same peak current value and produce the same spark energy and resulting hot spark. The microcontroller needs to know what the supply voltage is so it can properly set the coil charge time properly to ensure an adequate spark and adjust the firing delay appropriately when ATA mode is used. It turns out the microcontroller is equipped with an Analog to Digital Converter (ADC) that has the capability of sampling the battery voltage and converting it to a digital value that the microcontroller understands. The E-Timer monitors the battery voltage and adjusts the

coil charge time based on operating battery voltage. This is done at initial start up and during operation so the ignition timing can compensate for battery voltage droop during operation.

OBD-T

Cars with electronic ignition typically have on board diagnostics to monitor operational parameters and the E-Timer is no different. The computer stores serial number, timing mode, minimum and maximum operating voltage, temperature, RPM and a few other parameters for diagnostic purposes.

Performance Testing

Performance Testing – V10, V11: resulted in several early failures due to the omission of a critical component and component quality issues. These problems were corrected in version V12. The E-Timer has been tested on 6V and 12V cars with and without starters.

Test drivers immediately comment about the smooth operation even at extremely slow engine speeds that are void of the characteristic surging and bucking common with mechanical timers. Acceleration has been described as steady and aggressive with excellent top end performance. Several test initiatives are underway to determine the optimal Model T timing advance curve which results in best overall performance.

Battery power consumption is markedly reduced to approximately 1/3 compared with original timer/roller ignition system by having the E-timer scale back on repetitive sparking; only the first spark initiates combustion so subsequent sparks are at a reduced energy. Average 12V DC current dropped from 1.3A with original coil/points operation to only 0.5A with the E-Timer. That means less draw on the battery and longer battery life. Lower current draw is also less stressful on the coils resulting in cooler operation. The E-Timer will not melt the tar out of a coil operating on 12V if left accidentally buzzing for 1 minute although this is still not recommended.

Like other electronic ignitions, the E-Timer does not run on magneto but the

magneto can still be used to charge the battery via proper voltage regulator to maintain the battery during operation and because the coil points are bypassed (shorted) even “bad” coils with shorted condensers will work just fine if the coil windings are good; don’t throw them out!

Several aspects of the E-Timer were considered novel enough to warrant submission of a patent application which is pending. Locating the control electronics within the timer housing mounted to the engine raised reliability concerns due to the elevated operating temperature and oil or water contamination. Brass screws are used as the timer terminals. They serve a dual purpose of connecting to the ignition coils and getting the heat out of the timer housing. OBD-T diagnostic data indicates the maximum E-Timer temperature was measured at 65C following a 45 minute trip on a hot July day. E-Timer components are rated for operation at 105C to 125C. The circuit board and components are protected by a polyurethane conformal coating impervious to water and oil.

Beta testing is presently underway thanks to a few pioneering individuals who ordered a limited number of beta test units and helped keep the project alive. The E-Timer will hopefully enter the production phase later this year if beta testing proves successful. The estimated E-Timer cost as of this writing is \$399.95. Those interested in learning more about the E-Timer are invited to contact the author at mictel@comcast.net.

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Mike Kossor, WA2EBY holds a Master’s Degree in Electrical Engineering and has over 30 years experience designing innovative solutions to complex electrical problems ranging from highly linear microwave power amplifiers to automotive ignition control systems. Mike is skilled in analog, digital, RF and microcontroller disciplines as well as Visual Basic and C programming languages. He holds an Extra Class amateur radio license and can be reached at: mictel@comcast.net

Footnotes:

1. “The Model T Ford Ignition System & Spark Timing”, By Ron Patterson & Steve Coniff”, Model T Times, Nov-Dec 2003.
2. “More on Model T Ford Spark Timing”, By Ron Patterson; <http://www.mtfca.com/encyclo/ignition2.pdf>
3. For a detailed chronology of the E-Timer development, refer to: “History of Innovation and Inspiration”; By Mike Kossor; Model T Times No. 370 Aug/Sept 2010.