

# Testing Spark Plug Wires

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## Introduction

There has been much discussion of aftermarket ignition systems and wires on the mailing list, particularly with respect to the aftermarket Nology wires. People who have used them had varying results. Everything from massive EM interference that caused the ECU failures to cars running high boost who's owners had excellent results. Nology's print ads make claims about increased horsepower, stronger spark including numbers for arc temperature and current. The makers of the wires claim that a capacitor integrated into the wire is the secret.

I collected 4 different wires and conducted several tests and measurements on them to try and have some scientific and reproducible data. The results are surprising. The Nology wires do produce a stronger spark than a stock wire and the capacitor does have an effect. One reason that the Nology wires make a stronger spark is that they have a lower resistance than any other wire tested. With the capacitor portion of the wire disabled the wires still had the strongest spark. Grounding the capacitor wire did make the spark even stronger.

My test results were somewhat limited as I could not find an accurate way to measure the voltage and current flow due to the extremely high voltages. When the voltages become high enough, current flows can be produced by electrons bleeding off into the air or into any metal object which has significant mass. This leads to erroneous and irreproducible measurements. I'm working on building some special high voltage probes for the oscilloscope which should alleviate this problem, but for now some static measurements and pictures is all you get.

A stronger spark does not always equal more HP. If your stock ignition is reliably lighting the mixture, you can add as much spark energy as you want, but it won't make any more horsepower. To date no independent dynamometer test I know of has shown any increase in horsepower over stock wires that were working properly.

The Nology ad is reproduced below in the **Test Images** section. I'll let you make up your own mind regarding their claims.

## Spark Ignition Requirements

To ignite a stoichiometric air-fuel mixture (14:1) approximately 0.2 millijoules of spark energy are required. Very rich or lean mixtures can require as much as 3 mJ. Most coils are capable of storing 60 to 120 mJ of energy and will produce an output voltage of over 30 kilovolts. Spark duration for a coil storage ignition (where the spark energy is generated by the collapse of a built up magnetic field of the primary coil winding) runs between 1 and 3 milliseconds. Capacitive discharge systems tend to have shorter spark duration.

The energy generated by the coil must be delivered to the spark plug gap with enough energy to still ignite the mixture. Power is lost across the distributor gap, via leakage of the wires insulators and any in-line resistances such as the wires and resistors inside the spark plugs themselves.

Longer spark duration and larger spark distance both increase the probability that a given mixture will be ignited by the spark. Turbulence in the mixture itself also helps ignition, although too much airflow can blow out a spark or prevent it's formation.

## Anatomy Of A Spark

To understand spark plug wires, it helps to understand some of the physics behind a spark. You get a spark when an insulator breaks down and allows a rapid discharge of electrons across it. A spark consists of four distinct phases. The first phase is a sudden decrease in resistance, which leads to the second phase, which is marked by current runaway (a feedback condition where more current flow causes lower resistance and thus even more current flow). The third phase is indicated by a voltage collapse as the low resistance path discharges the built up energy and finally the fourth phase which is indicated by a low voltage with high current flow through the insulating material.

Here is a voltage vs. time [plot](#) of a typical spark from an automotive ignition coil. The voltage rises rapidly until breakdown of the the mixture occurs (1), which is followed by voltage collapse and stabilization at a high current and constant voltage (2). Spark duration ( $t$ ) runs about 1.5 mS.

The initial breakdown is caused a high electric field density. An electric field has a direct relationship to voltage. The higher the voltage, the stronger the electric field. Electric fields have a tendency to accelerate any charged particles within them such as free electrons or ions. As the particles are accelerated, they hit nearby atoms and knock electrons from them, which then are in turn accelerated by the field. If the field is strong enough, the reaction cascades until a large enough number of the atoms in the insulator are ionized to cause breakdown and conduction.

For a given voltage, field density is inversely proportional to the radius of the surface. Therefore, arcs are most likely to start at any corners or sharp points as these areas will have their greatest field density.

In a spark plug, gas (air and vaporized gasoline) provides the insulator which is broken down. Generally, the initial breakdown voltage is higher in gases with higher molecular weights, so adding gasoline to the mixture increases the breakdown voltage. Increased pressure also increases the breakdown voltage. The relationship of pressure vs. breakdown voltage is also affected by the distance between the two electrodes and a combined pressure X spacing number is used. At pressure X spacing values over 1 (N/m<sup>2</sup>)m the relationship is nearly linear, ie a 10 X increase in pressure will yield almost a 10 X increase in breakdown voltage. Air has a breakdown voltage of 1000 volts at a pressure spacing value of 10.

What all the above means with regard to igniting the mixture in a motor is; The higher the cylinder pressure and the more fuel there is, the higher the voltage needs to be to start a spark.

Once the arc is started, any airflow over the electrodes has a tendency to carry the ionized (conducting) gas away and blow the arc out. As soon as the arc breaks apart, the voltage rises again and the arc may re-form. If the airflow is high enough to carry the partially ionized gas away faster than it can re-form, the spark will blow out.

## Spark Plug Wires

Spark plug wires are made of a conductive core and typically silicone rubber insulation. The core is usually a carbon impregnated fiber or wire. The conducting core is bent over at the wire end and the boot metal is crimped over the core/insulation of the wire. Many aftermarket wires come with no boots, which allows one to add the boots of choice and cut the wires to the desired length.

Most OEM wires use a carbon fiber as this produces minimal RF noise. The down side of carbon fibers is high resistance and thus reduced spark energy. Solid wires have very low resistance, but typically produce unacceptable amounts of RF interference, frequently causing interference in radios (in the installed vehicle as well as nearby radios). This interference can also produce problems with any electronic equipment used inside the car such as fuel injection, panel meters and ABS systems. Spectral output from ignition wires can be anywhere from 10kHz to over 10GHz. Some wires use a solid metal core that is helically wound to cause the wire to look inductive at high frequencies and minimize EM radiation.

Silicones have a resistivity of  $10^9$  to  $10^{11}$  ohms per meter (between 1 and 100M ohms per mm). Given a core diameter of 2mm and insulation diameter of 7mm that's only 2.5mm of insulation from the core to the outside world and most wires actually leak a considerable amount of energy to their outer shell.

If the surface of the wires becomes contaminated, it can bleed a significant amount of power out of the wire to ground at any point it touches metal or a grounded surface. One way to check for this is to view the engine compartment in total darkness. Corona discharges will be seen at any larger bleed off points. No visible coronas are not a guarantee of no leakage however. If possible, it is best to keep the wires from touching any metal or coolant hoses (coolant is highly conductive with respect to air or silicone).

Here is an equivalent circuit [schematic](#) of the ignition system and a regular and Nology spark plug wire. The circuit shows why the Nology wires capacitors produce a stronger spark.

The Nology wires capacitors are formed by simply wrapping a wire braid around a segment of the wire and then grounding it. Construction is very similar to coaxial cable. This braid forms one side of the capacitor plate and the center conductor forms the other. Nology uses a carbon fiber type center conductor, but it has a much lower resistance than the other fiber wires tested. The braid also acts as a shield to prevent EM radiation. The capacitance is evenly distributed along the length of the braid and the center conductors resistance is distributed along it's length. The equivalent circuit above is a theoretical representation of this. In an ideal simulation there would be an infinite number of very small capacitors and resistors which would all add their effect to define the model of the wire.

The capacitors become charged during the initial voltage rise. When the gas breaks down and current starts to flow across the spark gap, the coil energy must flow through the coil wire resistance, the distributor gap and the resistance of the individual spark plug wire. The capacitors however, discharge directly through the gap, with only a short piece of the plug wire providing resistance in their path.

The measured value of 35pF of capacitance is misleading in the fact that although the wires have 35pF of capacitance at the 2 volts that the capacitance meter measures them with, as the voltage increases, the wires leak more, thus decreasing the effective capacitance as the voltage rises. The calculated value of energy storage for a 35pF capacitor at 15kV is  $1/2CV^2$  or about 4 J, well in excess of the storage capacity of the coil itself. Although one might expect the capacitors to absorb a significant part of the coil energy and cause considerable voltage droop, they don't. As the pictures below show, the Nology wires could develop a spark across a 20mm gap. When I get a chance I will run a computer simulation of the set up to see what kind of results it predicts.

### Static Test Results

Wire	Length	Resistance	Capacitance	Insulation Breakdown	Insulation Thickness
Toyota	380mm	21 Ohms/mm		30 kV+	7.0mm
Nology	430mm	1.2 Ohms/mm	35 pF	30 kV+	7.6mm
Accel	785mm	11.3 Ohms/mm		30 kV+	8.7mm
Generic	540mm	17 Ohms/mm		30 kV+	6.9mm

## Nology Wire Test Images

The visual results from all of the wires tested except the Nologys were similar, so I did not produce pictures for all of them. Only the Toyota stock wires (Sumitomo R-16 X-S) and Nology wires are shown below.



The Nology wire ad. From Turbo magazine, December 1996, page 49.

The wires were tested at two engine speeds and two gap sizes.



Nology wire at .05" (1.27mm) gap, 1K RPM effective engine speed.



Nology wire at .80" (20.32mm) gap, 1K RPM effective engine speed.



Nology wire at .05" (1.27mm) gap, 8K RPM effective engine speed.



Nology wire at .80" (20.32mm) gap, 8K RPM effective engine speed.

## Toyota Wire Test Images

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Toyota wire at .05" (1.27mm) gap, 1K RPM effective engine speed.



Toyota wire at .80" (20.32mm) gap, 1K RPM effective engine speed.



Toyota wire at .05" (1.27mm) gap, 8K RPM effective engine speed.



Toyota wire at .80" (20.32mm) gap, 8K RPM effective engine speed. During this test, the arc plasma ignited the plastic of the spark gap test fixture. This caused the center of the arc to darken as the conductive gas escaping from the burning plastic diffused the arc.

## The Test Set Up

The test set up consisted of a signal generator, a transistor buffer circuit, a Mallory Hy-Fire III ignition box, a stock MkI coil, a current shunt and an adjustable spark gap.

The signal generator provided a variable frequency pulse source to drive the ignition, in effect simulating the distributors output.

The buffer circuit was used to isolate the signal generator from the ignition box itself, as I have blown out ICs connected directly to the ignition box. The buffer was a 2N2222 set up in common emitter mode with a 10K pull up resistor on the collector.

The Mallory Hy-Fire is a single spark ignition system. A large darlington transistor is used to ground the negative side of the coil's primary winding. The positive side of the coil was connected directly to the power supply. When a trigger pulse arrives, the ignition opens the darlington causing the coil to produce a spark. The Hy-Fire adjusts the dwell timing according to the input pulse frequency.



## What's Next

As soon as I develop a reasonable measurement method for voltage and current I will try and re-test the wires. This should also give me the ability to test coils for how much energy they can store, voltage output and spark duration.

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