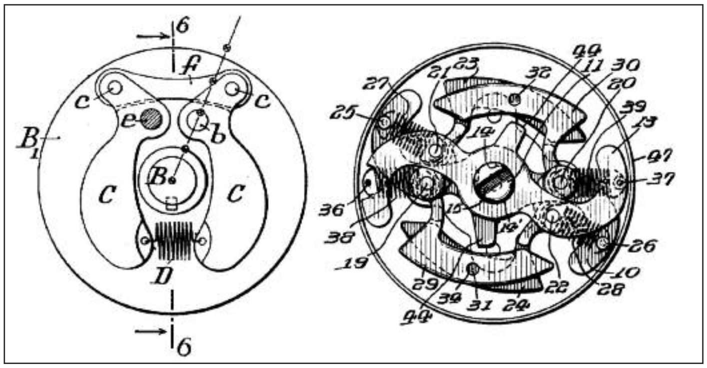
# Stroke, Spark and Springs

### By Bruce Smith

The centrifugal spark-advance distributor has been used in the internal combustion engine for over 100 years. The familiar concept hasn't changed much since the early days, using a timing mechanism based on pivoted arms cast outward during rotation. By affixing the distributor drive shaft to one part of the pivot and a second driven shaft to the other, spark can be advanced to cylinders through a conducting rotor. The angular offset between the driving and driven shafts is increased with rotational speed via centrifugal force, countered by one or more extension springs. Pivots, weights, and contact surfaces are important maintenance elements to ensure proper performance but since the springs can be prone to distortion and failure, they need particular attention in a decades-old distributor.

An early design for a centrifugal advance distributor is seen in the figure below from a 1912 Bosch patent. The advance mechanism uses a pair of weighted arms and a single spring. Pivoted arms C are fixed separately to a driving shaft plate and to an advance plate by pins b and e. Centrifugal force casts the arms outward, increasing the angular separation between the plates. The advance is balanced with a spring mounted between the arms. The extension range can be reduced using a pair of springs (one for each arm) or a more elaborate system with multiple springs, like the one below from a 1916 Atwater Kent patent. This four spring design has a driven top plate attached at points 21 and 22 and the distributor shaft affixed to points 19 and 20. Variations evolved over the years, including the use of asymmetrical weights, unequal springs, and unique pivoting designs.

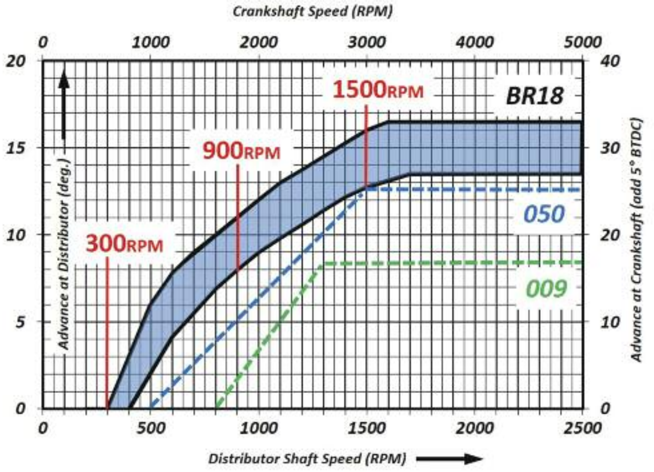


A single spring centrifugal advance mechanism from a 1912 Bosch distributor patent (left) and a four spring example from a 1916 Atwater Kent patent (right).

In these examples, spark advance is controlled mechanically by a tension load applied to the extension springs. Distributors using spring tension to restrict outward motion exhibit near straight line advance from an initial state to the end point. Variations to arm design, weights, mechanical stops, and spring dimensions can adjust the onset, advancing rate, and endpoint. But if matched arms and springs are used, trends will be linear with rotational speed. The reason for this is based on simple mechanical spring laws. Under tension, a spring constant is measured by the force exerted by the spring divided by its displacement, in units of N/m. Helical extension springs, like those used in distributors, will have a linear spring rate once an initial spring tension is overcome. Used to counter centrifugal arms in a mechanical distributor, this will lead to a brief rise in advance angle and then a straight line increase until a mechanical hard stop is reached.

Shown below are photos of the advancing mechanisms for Bosch 0 231 178 009 (or 009) and Bosch 9 230 081 050 (or 050) centrifugal distributors. These distributors were designed for VWs but have been used over the years in Porsche 1600 motors. Designs are similar, with the 009 using a single spring and the 050 using a pair of springs. The corresponding advance curves below show how neither is an ideal choice for normal driving performance in a 356 or 912. Both exhibit a straight line increase in advance angle from an onset until an end point. The 009 is linear from about 800 to 1300 rpm before reaching a maximum at about 8.5° at the distributor. Though this may be OK for high revving use with a large initial advance, the performance at the low end is sacrificed. The 050 increases RPM to about 1500 rpm with a limit of 13° at the distributor. The upper limit is below the factory spec but OK for today's lower octane gas. These plots are shown along with the factory range for the distributors used in Porsche 1600 motors, specifically the VJ 4 BR18 (or BR18), the 0 231 129 022 (or 022), and the 0 231 129 031 (the 031). There are clear differences when these BR18-type distributors are compared to the 009 and 050, especially in the mid-ranges where adjustments in static timing cannot make up for performance losses. The differences lie with the design of the spring behavior.

The straight line advance of Bosch 009 (left) and 050 (right) distributors are a result of spring tension countering centrifugal motion of weighted arms.



Advance curves for Bosch BR18-type, 050, and 009 distributors showing differences between linear response and factory specs for the Porsche 1600.

## More than tension

Linear spark advance has its limits and is usually not the best choice for top engine response. There is generally a compromise between the response at low and high revs, and the ability to offset this with static timing. To achieve a non-linear response throughout the rev range, Bosch added a secondary effect to the springs' influence on the angular advance in some distributors. The Bosch BR18 and 022 cast iron distributors and early 031 aluminum bodied units are among those unlike simple linear advance distributors. Their rise in response is more graceful, exhibiting initial aggression at the low revs and a slower sweep toward a maximum at the top end. Their behavior is not a straight line, as would be predicted from a simple spring calculation. It takes a second spring property to achieve such an attribute.

So what is this added spring effect? Inspection of the motion of the advance mechanism reveals the answer: flexure. A bending component is employed to help counter outward arm motion from the mid-rev range to endpoint. The rotor shaft is attached to a top plate with cam tongues that transfer spring bending into to rotational resistance. As the springs roll onto these tongues, the added resistance results in a smoother transition toward the maximum advance. This is pictured below with a BR18-type distributor mounted on a Sun 404 distributor tester, which is rotationally ramped through its rev range. A series of 'stop-motion' flash-photographs were taken at 100 rpm increments, including those shown here at 300, 900, and 1500 rpm. These points correlate to the earlier plot, where at 300 rpm the advance arms begin to move outward under tension. At 900 rpm, the springs have made contact with the edge of the tongues on the top plate, adding a bending force. The gap between the arms and the distributor body is reduced while the angle of the advance plate is increased by 10°. At 1500 rpm, the springs are strongly rolled onto the tongues, slowing the advance toward its limit of 15°.

**Flash photographs of a BR18 distributor at 300 (left), 900 (center), and 1500 (right) RPM showing the behavior of the extension springs and advance angle.**

## A closer look

Since these springs do double duty, their properties are generally more critical than those used in simpler distributors. Bosch used 21 coils of 0.017" high-carbon spring wire (aka music wire) with a coiled diameter of 0.158" terminated with a single loop on one end and a double loop on the other. The outer flexed ends of the springs get the most abuse and are a common area for stress failure so the double loop is used. A common goal for the service life of an ordinary extension spring is often one hundred thousand to one million cycles. Spring failure can be influenced by cycling, applied load, deflection, temperature extremes, and corrosion. So how long should a spring last in the life of a BR18 or 022 type distributor? If a single spring cycle is counted as revving within the 600-3000 rpm range (300-1500 rpm at the distributor), how many cycles are common in a 1600 motor? If revved just once per mile (up or down), the lifetime of a distributor spring may be 100K miles. Maybe the answer is a million miles, but the occurrence of broken springs in many rebuilds suggests many fewer. Added together with the stress at spring ends and the likelihood of corrosion over years of use, it's best to consider distributor springs as consumable items.

## DIY springs?

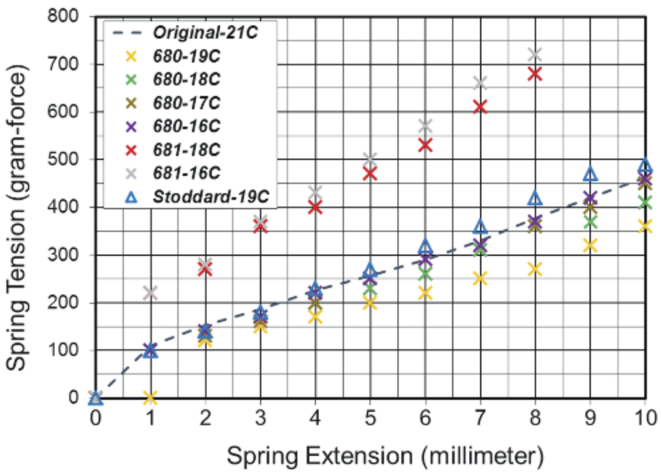
First thoughts may be that DIY springs belong nowhere near a Porsche. This might be true if the only option were to coil music wire around a mandrel to the correct dimensions, heat treat, and form the ends. But stock extension springs are commercially available covering a variety of composition, wire gauge, and overall diameter. The project then becomes one of matching spring dimensions, cutting to size, forming loop ends, and testing. Since loop ends are just single bends of one or two coils, the biggest challenge becomes an ocular one. This is a task probably best suited for eyes under 30 years old but made possible with strong magnification.

Springs need high tensile strength and a high elastic limit to withstand the stresses and repeated loadings in the dynamic conditions of a distributor. Several suppliers provide high-carbon springs with wire gauge and overall diameters near those of Bosch BR18-type springs. In particular, the W.B. Jones Spring Company stocks 11" lengths of extension springs with wire/overall diameters of 0.018"/0.156" and 0.016"/0.156", close to the dimensions of the 0.017"/0.158" Bosch factory springs and costing just 14¢ an inch. The number of coils in a spring will influence tension and flexure performance as well. A series of DIY spring pairs were fashioned to cover a variety of dimensional combinations. For comparison, replacement springs available through Stoddard were also acquired, as were originals from a several BR18 and 022 distributors believed to contain factory springs. Spring tension was measured using the pulling force setup pictured below. The corresponding plot compares the force needed for extension of original Bosch springs, 0.016"/0.156" DIY springs with 16 to 19 coils (labeled 680-16C through 680-19C), 0.018"/0.156" DIY springs with 16 and 18 coils (labeled 681-16C and 681-18C), and Stoddard replacement springs with 19 coils.

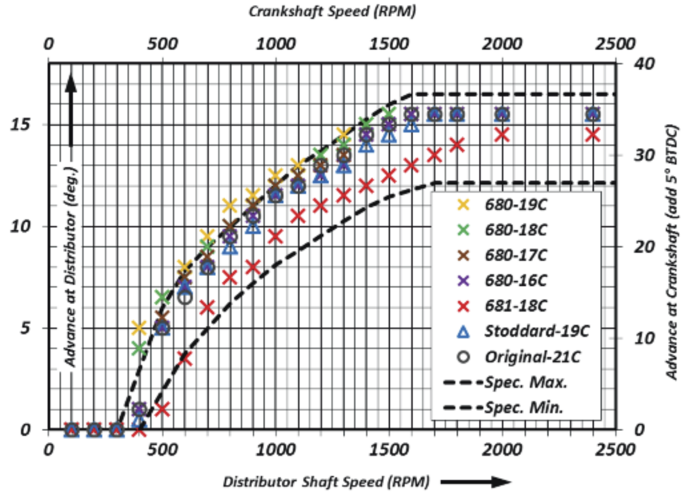
**Commercially available stock springs (bottom) and the testing arrangement using a pull force gauge to measure and compare spring tension force.**

Results show several springs behave similar to the original factory springs, including several of the 680 DIY springs and the Stoddard replacement. Since this exercise only measures spring tension and not bending, the real test is in the performance in a distributor. Pairs of each spring type were installed into a working Bosch 022 distributor and advance curves were measured on a Sun 404 tester. The results shown at right are consistent with the pulling tests, where fewer coils and thicker wire resulted in reduced advance performance. Here, the best spring choices to match the original springs are 680-18C, 680-17C, 680-16C and the Stoddard springs. It is interesting to note the latitude over a few spring coils as the factory included tolerance to account for parts and performance variation. This particular distributor runs on the high side but within spec limits.

*Continued*



Plots of the pull force required for DIY springs compared to Stoddard and factory originals.



Advance curves for an 022 distributor using a variety of spring types showing several to be adequate choices to meet the original spec.

## Beyond factory specs

This exercise sought to cast some light onto the unique inner workings of the distributors we use in our cars. Since adequate replacement springs are currently available, cost may be the only incentive to fashion your own springs for factory-like performance. There are however opportunities for improvement, especially with stronger springs to reduce advance and allow for higher static settings. Combined together with shimming at the limit stop, as discussed for example in Kit Sodergren's 2013 *Registry* article (issue 37-3), better performance can be designed into the entire rev range. Though a more involved and sacrificial process, modifying the shape and/or weighting of the advance arms can provide other opportunities as well.

***Bruce Smith** is an engineering professor at Rochester Institute of Technology. His website is www.sparkingplugs.com.*

---

## Membership Renewal / Join Form

Membership questions? email
Membership@Porsche356Registry.org or call **651-342-1524**

***Go to www.Porsche356Registry.org for fast and easy membership changes!***

NO INTERNET ACCESS? PHOTOCOPY this page and mail to **356 Registry, PO Box 356, Stillwater, MN 55082**

**This is a** (choose one)**:** _____ **New Membership.** _____ **Renewal. You may join or renew for up to 3 years.** _____ **Gift.** Please call 651-342-1524

Name ____________________________________________

Address ____________________________________________

City ______________________ State / Province ______________ Zip / Postal code ______________

**Your EMAIL address** ______________________________ (Email is the **BEST** way for us to stay in touch)

We do **NOT** sell or rent our members' private information

| | | |
|---|---|---|
| USA via Periodical mail | @$45 / year. | _______ years = $ ________ |
| USA via First Class mail | @$60 / year. | _______ years = $ ________ |
| Canada / Mexico | @$55 / year. | _______ years = $ ________ |
| International | @$65 / year. | _______ years = $ ________ |

Country ______________________

Check/Money Order enclosed _____ Charge credit card the total amount above: VISA ____ MASTERCARD ____ DISCOVER ____

Card number ____ ____ ____ ____ - ____ ____ ____ ____ - ____ ____ ____ ____ - ____ ____ ____ ____ Exp. date ____ / ____

Signature for credit card ______________________________ Date ______________________