

[54] **COAXIAL ELECTRIC ARC
DISCHARGE DEVICES**

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[22] Filed: **Nov. 23, 1970**

[21] Appl. No.: **91,977**

[52] U.S. Cl. **313/178, 313/197, 313/217**

[51] Int. Cl. **H01j 17/12**

[58] Field of Search.....313/174, 178, 197, 198, 217

[56] **References Cited**

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[57]

ABSTRACT

Triggerable electric arc discharge device includes coaxial cathode and anode electrodes defining therebetween a hollow cylindrical primary arcing gap. A trigger assembly having an elongated longitudinal configuration is inserted into a longitudinal bore formed in and adjacent to the surface of the cathode electrode so as to be partially exposed into the inter-electrode gap. Trigger assembly includes a ceramic hollow cylinder surrounding a metallic trigger electrode. Trigger gap is defined by extension of the trigger electrode past the inboard end of the trigger ceramic insulator and a trigger gap exists between the extended portion of the trigger electrode over the inboard end of the ceramic insulator and to the body of the cathode electrode. A voltage is connected between anode and cathode electrodes and a relatively low voltage pulse is supplied to the trigger electrode, causing breakdown of the trigger gap. Trigger arc formed thereby causes propulsion of ionized specie into the main gap and breakdown thereof.

9 Claims, 3 Drawing Figures

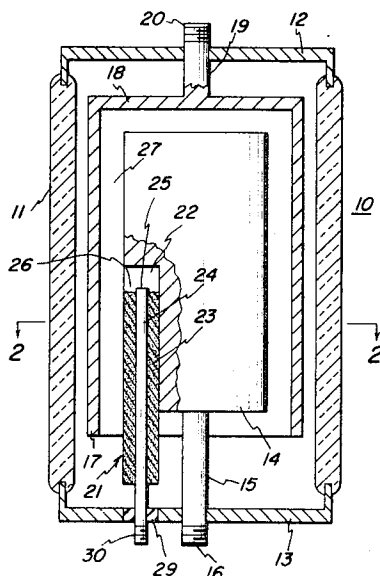


FIG. 1

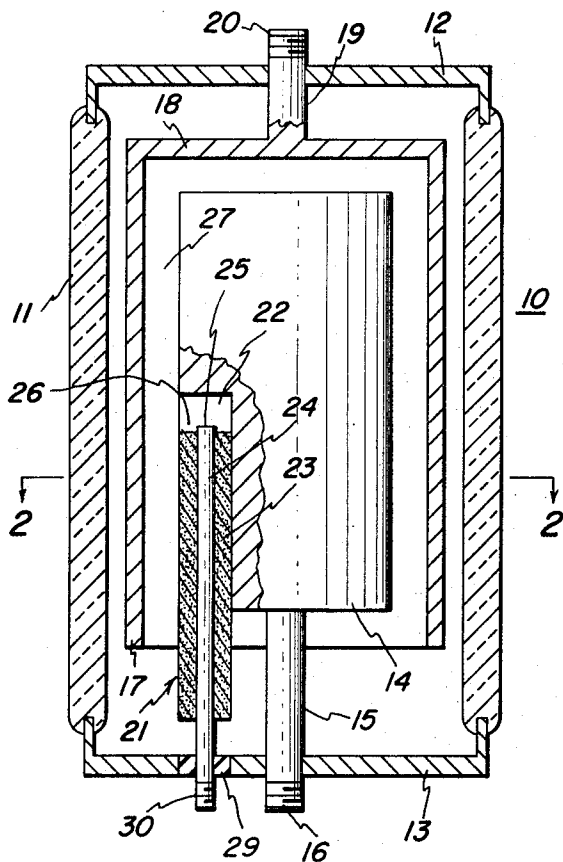


FIG. 3

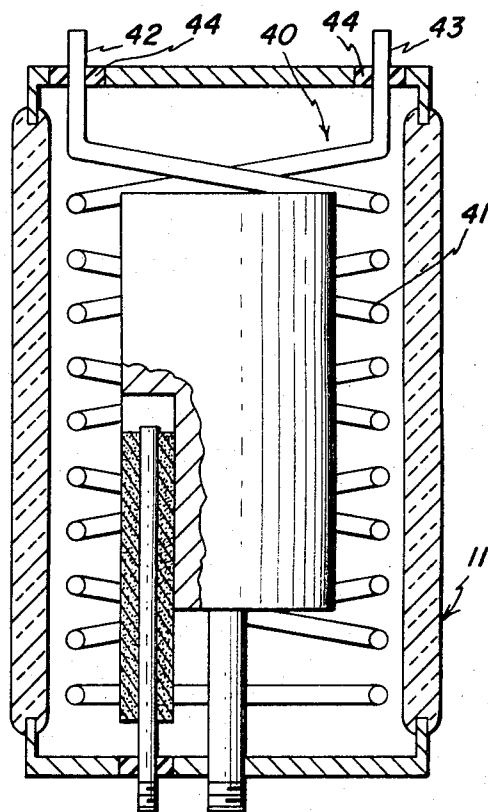
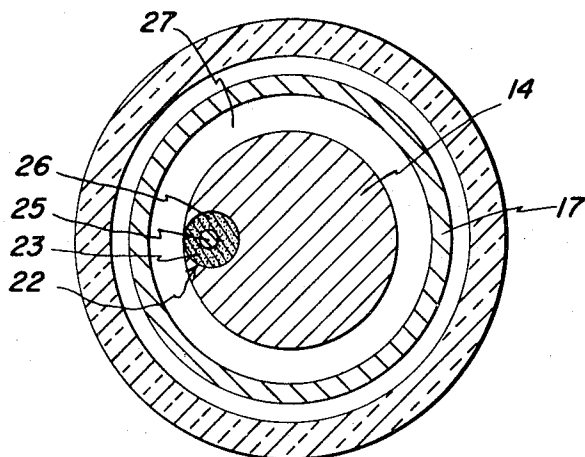


FIG. 2



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COAXIAL ELECTRIC ARC DISCHARGE DEVICES

This invention relates to triggerable arc devices adapted to change from a non-conducting state to a conducting state by a triggering pulse of voltage. More particularly, the invention relates to such structures as utilize a coaxial arrangement of anode and cathode electrodes.

This invention is related to the co-pending, concurrently filed application of J. M. Lafferty, Ser. No. 91,978, filed Nov. 23, 1970.

In the electric switching art, triggerable arc discharge devices are well-known. One such device specifically adapted for establishment of a vacuum arc is disclosed and claimed in Lafferty U.S. Pat. No. 3,087,902. The devices of this general class are useful in that they are adapted rapidly to render conductive a voltage circuit of tens or hundreds of kilovolts at currents of tens or hundreds of kiloamperes by the application of a short pulse of the order of a few hundred or few thousand volts at values of less than one ampere current. Additionally, triggerable arc devices switch electronically, so that the speed of switching attainable is very rapid and may be accurately controlled. In triggerable vacuum arc devices, the removal of the sustaining voltage or current, as by the attainment of a normal "current zero" of an alternating supply, allows for deionization of all conduction carriers and extinction of the current carrying arc.

One problem attendant the operation of triggerable arc devices has been the failure thereof due to erosion of the trigger electrode because of its being exposed to the effects of the main or primary arc. A related problem has been the deterioration of the devices, also including the trigger assemblies thereof, by very high current densities in the primary arc. Although, much work has been done, and many worthwhile advances have been made, in general, there is need for triggerable arc devices in which trigger erosion is minimized or controlled for very long life operation. Similarly, and consistent with the foregoing, there is need for triggerable arc devices in which current densities are reduced and in which transfer of a primary arc from a point of ignition to a point of extinction, at which current density is maintained at a low value, is effectuated smoothly and effectively.

Accordingly, it is an object of the present invention to provide electric arc discharge devices of the triggerable type wherein trigger arc initiation means, adapted to survive a long operating life, is provided.

Still another object of the invention is to provide triggerable arc discharge devices having primary arc-electrodes defining broad area arcing gaps for low current density operation.

Still another object of the invention is to provide improved triggerable vacuum gap devices.

A further object of the invention is to provide improved sublimation getter pumps.

Briefly stated, in accord with one embodiment of the invention, I provide a coaxial structure for a triggerable electric arc discharge device in which a trigger assembly is imbedded in a bore adjacent to, and intersecting, the exterior surface of the inner, cathode electrode thereof. The trigger assembly includes a metallic trigger electrode surrounded by a hollow ceramic cylinder. The trigger electrode defines, with the cathode electrode, across the inwardly depending sur-

face of the ceramic cylinder, a trigger gap. Pulsing the trigger electrode, while a high voltage is applied between cathode and anode electrodes, with a voltage pulse initiates a trigger arc across the ceramic cylinder. Cathode specie is evolved therefrom due to the trigger arc, and the hollow cylindrical gap between the anode and cathode electrodes become conducting and a primary arc is established. Due to the concentric cylindrical arrangement of the cathode and anode, the arc rapidly spreads out over the cylindrical primary gap, reducing the current density therein. With repeated triggering operations, the trigger electrode and trigger ceramic cylinder tend to erode away. Due, however, to the elongated structure thereof, erosion of the trigger only shifts, longitudinally, the point at which the trigger arc is stuck.

In accordance with another embodiment of the invention, the anode electrode is permeable, as for example, in the form of a helical coil. When such anode structure is used, and when the cathode is an active, gas-gettering substance, cathode material is vaporized from the cathode, passes through the anode and deposits on the surface therebehind as a fresh gettering film. All gases, other than noble gasses, are readily gettering by such a fresh metallic film. When such a structure is utilized in accord with the present invention, the device may be utilized as a highly effective sublimation vacuum pump.

The novel features believed characteristic of the present invention are set forth in the appended claims. The invention itself, together with further objects and advantages thereof, may best be appreciated by referring to the attached drawing in which:

FIG. 1 is a vertical cross-sectional view, with parts broken away, of a triggerable vacuum arc device constructed in accord with one embodiment of the present invention;

FIG. 2 is a horizontal sectional view of the device of FIG. 1, taken along section lines 2—2 and;

FIG. 3 is a vertical cross-sectional view of an alternative device in accord with the invention.

In FIG. 1, a vacuum arc device constructed in accord with the present invention is illustrated at 10. Although devices in accord with the present invention may be utilized to operate in a low pressure gaseous medium or a vacuum, for sake of clarity and ease of description the device will be described in the embodiment in which the device is operated in a vacuum environment. Triggerable vacuum arc device 10 includes a cylindrical insulating sidewall member 11, closed at either end in hermetic seal with respective metallic end wall members 12 and 13. An elongated cylindrical cathode electrode 14 is supported along the longitudinal axis of device 10 and is mounted upon cathode support member 15, which is electrically and mechanically affixed to end wall member 13 and emerges therethrough as cathode terminal 16. Alternatively, support member 15 may pass through end wall member 13 in a suitable hermetically sealed insulating bushing so that cathode terminal 16 is electrically isolated from end wall member 13. A cylindrical anode electrode 17, closed at one end thereof with planar end cap 18 is supported within device 10 by anode support member 19 which is electrically and mechanically affixed to end wall member 12 and emerges therethrough as anode elec-

trode contact 20. As with cathode support 15, anode support member 19 may, alternatively, be passed through end wall member 12 through an insulating hermetic seal to isolate contact 20 from end wall member 12.

Cylindrical anode electrode 17 is concentric with longitudinally disposed cathode electrode 14 and defines therewith a primary breakdown gap 27. A trigger assembly 21 is longitudinally disposed in a bore 22, cut in the body of cathode electrode member 14 with the center of the bore slightly less than one-half the diameter thereof from the cylindrical exterior surface of cathode electrode member 14, so that there is communication between bore 22 and inter-electrode gap 27 by means of a longitudinal slot which is relatively small with respect to the diameter of the bore. Conveniently, the slot is approximately one-fifth or less the diameter of the bore. Trigger assembly 21 includes an insulating, hollow, cylindrical ceramic member 23 which is inserted into bore 25 a distance less than the full length of the bore. Although bore 22 is shown as terminating slightly more than one-half the distance into cathode 14, bore 22 may, if desired, extend the entire longitudinal length of cathode member 14. In any event, the inboard end of ceramic cylinder 23 is terminated approximately one-half the length of cathode electrode 14. This is so that the trigger gap 26, which is located thereat is located in the general vicinity of the mid-point of the inter-electrode gap.

A trigger electrode 24, which is composed of a metallic substance and is preferably a refractory metal such as tungsten or molybdenum, is inserted centrally into the aperture in ceramic cylinder 23 and extends slightly past the inboard end thereof to form trigger button 25. Trigger button 25 defines, with the surrounding portions of cathode electrode 14, over the inboard surface of ceramic cylinder 23, an annular trigger gap 26. Trigger electrode 24 is passed through end wall member 13 in insulating, hermetic seal through bushing 29 and terminates in trigger electrode terminal 30.

In FIG. 2, which is a section view taken along section line 2—2 in FIG. 1, the juxtaposition of the anode and cathode electrodes and of the trigger electrode assembly may be more readily appreciated. From FIG. 1, it may be seen that cathode electrode 14 is concentric with anode electrode cylinder 17 and the two define therebetween a primary or main arcing gap 27. It may also be seen that bore 22 within cathode electrode 14 extends slightly into the inter-electrode gap and that there is communication between the gap and trigger button 25 over trigger gap 26 which is over the inboard surface of ceramic cylinder 23.

The device of FIG. 1 is constructed of materials which are consistent with a vacuum environment. Thus, for example, the cathode and anode electrodes and their support members, which are likely to be subjected to arcing currents, are prepared from conductive material, preferably having a high vapor pressure, such as equal to or in excess that of copper, but not as high as that of magnesium. In addition to copper, the electrode material may be any of the materials set forth in U.S. Pat. Nos. 2,975,256 Lee et al.; 2,975,255 and 3,016,434 Lafferty; and 3,140,373 and 3,497,755 Horn, or any such material which is adapted to produce

high concentration of conduction specie. Prior to fabrication, the high vapor pressure material is processed, for example, by repeating zone refining or vacuum melting steps to remove all sorbed gases therefrom or at least, reduce the same to a concentration of less than one part per million. This is so that during arcing, sorbed gases do not evolve therefrom to spoil the vacuum within the device. The device is fabricated utilizing conventional processes for fabrication for glass-to-metal seals and the like, and evacuated to a pressure of the order of 10^{-5} torr or less.

In operation, a high voltage, as for example, a high voltage transmission line voltage of tens of thousands of volts, for example, may be connected across device 10. In one embodiment, device 10 may be utilized to protect a plurality of power-factor correcting capacitors, also disposed across a high voltage transmission line, from over-voltages due to lightning strikes or other such failure-type incidents. In these incidents, it is desirable that the over-voltage may be short circuited from the capacitor devices, conveniently through a device such as illustrated at 10 in FIG. 1. Upon the occurrence of a failure incident and sensing thereof, an instantaneous pulse of, for example 1,000 volts, is applied between the cathode electrode 14 and the trigger electrode 24 causing the establishment of a trigger breakdown across the ceramic gap 26. As is well-known in the art, the intersection of the metal and ceramic surfaces causes a unique field distribution which is highly conducive to field breakdown. Upon the establishment of a trigger arc across gap 26, the metal of copper cathode electrode 14, of which it is conveniently constructed, is caused to vaporize and is ionized by the applied voltage. Due to the confined volume of the remaining portion of bore 22, a burst of ionized copper vapor is ejected into primary gap 27 across which high voltage exists. The gap 27 immediately becomes conductive. Due to the concentric configuration of the cathode and anode electrodes, there are no magnetic fields which interact with arcing currents present, due to the arcing currents or to the currents through the electrodes, upon the establishment of a primary arc. Once established, therefore, the arc primary diffuses readily over the broad area of the concentric cylindrical electrodes involving substantially the entire space therebetween. Preferably, the distance between the upper surface of arc cathode 14 and anode end member 18 is larger than the inter-electrode gap 27 so that no conduction currents exist between the arc cathode and end wall member 18. Such freedom is required in order to maintain the entire inter-electrode gap field free.

Upon the occurrence of the first "current zero," when the alternating current of the transmission line changes polarity and passes through the zero point, instantaneously, arcing current ceases. Due to the fact the conduction carriers in the gap 27 are all ionized metallic specie from the cathode and anode, instantaneous cooling and de-ionization occurs and, upon the initiation of the next current half cycle, the high dielectric strength of the vacuum prevents re-ignition of the arc.

Each time the trigger electrode is caused to fire, some of the material of the ceramic cylinder and of the trigger electrode are eroded away. This amount of

material is not, however, great and the erosion thereof is a relatively slow process. Nevertheless, substantial erosion of the trigger electrode assembly may occur without effecting the characteristics of the device of FIG. 1. Thus, as the trigger electrode erodes away, both the trigger electrode and the ceramic cylinder become shorter, but all that results is that the point of ignition slowly falls from the mid-point of the inter-electrode gap and moves along the longitudinal length of the trigger electrode. Since the trigger electrode is relatively long with respect to the arc cathode, substantial erosion may be permitted without any danger of failure of the device.

In FIG. 3 of the drawing, an alternative embodiment of the device is illustrated. In FIG. 3, in which like elements to those of FIG. 1 are identified with like reference numerals, the structure is identical to the structure of FIG. 1 except for the structure of anode electrode 40. Anode electrode 40 in FIG. 3 is a vapor and particle pervious matrix which is conveniently illustrated as a helical coil including coil member 41, fabricated, for example, from $\frac{1}{8}$ inch copper tubulation, and terminating in a pair of anode terminals 42 and 43, each of which are passed through insulating bushing 44. Although any permeable structure may be utilized, a tubular copper helix is ideal in that it facilitates forced fluid cooling.

In operation of devices in accord with the present invention, there are generally three prime failure mechanisms. In the first, the trigger electrode assembly may be degraded. In the device of the invention, this has been avoided by the unique longitudinal erodable configuration of the triggerable electrode assembly. Secondly, the arc cathode may be depleted due to the evolution therefrom of ionized specie in the operation of the device. This has been compensated for in the device of the invention by virtue of the rather massive construction of the cathode electrode. In the third failure mechanism, destructive anode spots and consequent melting of the anode, may be caused by some unique incident such as a gradual change in the surface characteristics of the anode such as by the deposition of material from the cathode thereupon to cause the unique and undesired field configuration which leads to concentration of current paths. Since melting of the anode electrode is to be avoided, in accord with one embodiment of the invention, such melting is rendered less possible by the passage of cooling fluid through the tubular anode, thus maintaining the anode at a relatively cool temperature and making less probable any melting mechanism.

The structure illustrated in FIG. 3 of the drawing is particularly advantageous if, rather than developing a triggerable vacuum gap as is illustrated in FIGS. 1 and 2, it is desired to utilize the broad principles of the present invention to construct a sublimation getter pump.

As is well-known to the art, a sublimation getter pump functions utilizing the process of the progressive vaporization of material from the vicinity of the cathode electrode, its acceleration away therefrom by the electrostatic forces of anode-to-cathode field, and the deposition thereof upon a suitable surface to form a fresh metallic film. Such fresh films have a unique and highly favorable characteristic for the gettering of ac-

tive gases, namely, all those gases other than the noble gases. In accord with the co-pending, concurrently-filed application of J. M. Lafferty, Ser. No. 91,978, filed Nov. 23, 1970, a permeable anode structure is utilized and a cold cathode is likewise utilized to cause the evolution of a copious quantity of vapors from a titanium, zirconium, beryllium, cerium, hafnium, aluminum, magnesium, tantalum, or other active gas gettering metallic cathode electrodes to form such an active gas gettering film. Although the concept of the cold cathode discharge for utilization in a sublimation getter pump is that of the aforementioned J. M. Lafferty and is not a portion of my invention, the structure of the present invention is uniquely adapted to trigger cold cathode discharges between a massive active gas gettering cathode electrode and a vapor permeable anode in the operation of a sublimation getter pump. Accordingly, the structure of FIG. 3, without the side wall member 11, may be utilized to perform the sublimation vacuum pumping function similar to the device of the Lafferty invention. In most instances, the surface upon which vapor is deposited will be a part of the vacuum system being pumped. Alternatively, side wall member may be used if a short term operation is to be utilized.

One device constructed in accord with the invention had the configuration illustrated in FIG. 3. This device utilized a five-eighths inch diameter, 4-inch long cathode electrode, a one inch inner diameter, 6-inch long anode electrode composed of a helical spiral of $\frac{1}{8}$ -inch copper tubing, and a 4-inch long 0.100-inch ceramic insulator cylinder surrounding a 0.060-inch tungsten trigger electrode wherein the ceramic was high purity (94 percent or better) aluminum oxide ceramic and extended approximately 2 inches into the length of cathode electrode 14 so as to reach the substantial mid-point thereof. The bore 25 further extended one-fourth inch past the mid-point. The described device operated successfully to trigger breakdown of a voltage of 120 volts at currents of 100 amperes for in excess of 70,000 operations with a loss of less than one-sixteenth inch in length of the trigger electrode assembly and without in any way adversely affecting the mechanical or electrical operating characteristics thereof.

By the foregoing, I have disclosed a concentric electrode structure for a triggerable arc discharge device which may take the form of a triggerable vacuum device or a sublimation vapor pump which has unique characteristics of providing a long-lived trigger, means for rapidly and without loss of energy transferring an initiated arc to a broad area inter-electrode gap at which arc extinction occurs and which avoids the formation of destructive anode spots and melding thereby.

While the invention, as disclosed herein with respect to certain specific embodiments and configurations thereof, many modifications and changes will readily occur to those skilled in the art. Accordingly, by the appended claims, I intend to cover all such modifications and changes as fall within the true spirit and scope of the foregoing disclosure.

What I claim as new and desire to secure by Letters Patent of the United States is:

1. A triggerable electric arc discharge device comprising: a first electrode having an exterior surface and

a bore therein extending adjacent said exterior surface and intersecting said exterior surface to define an opening in said exterior surface communicating with said bore; a trigger assembly including a trigger electrode with a portion thereof protruding from a ceramic body surrounding said trigger electrode, said assembly partially filling said bore so that there remains an unfilled portion of said bore and an unclosed portion of said opening communicating with said unfilled portion, said unfilled portion defining a trigger gap between the protruding trigger electrode portion surrounded by the ceramic body and the first electrode; a second electrode surrounding said exterior surface and spaced therefrom to define an arc gap which communicates with said trigger gap through said unclosed portion of said opening; means for supplying an arcing voltage between said first and second electrodes; means for supplying a pulsed trigger voltage to said trigger electrode; and, means hermetically enveloping at least portions of said first, second and trigger electrodes together with said arc and trigger gaps as well as the unclosed portion of said opening communicating said gaps, said means being evacuated.

2. The device according to claim 1 wherein said first and second electrodes are cylindrical and wherein said trigger electrode extends within said bore in said first electrode for a distance of approximately half the length of said first electrode.

3. The device according to claim 1 wherein said first and second electrodes are fabricated from high-purity gas-free metallic materials having a vapor pressure at least as high as that of copper.

4. The device according to claim 1 wherein said second electrode is a permeable structure adapted to pass particles and vapors ejected from the first electrode therethrough.

5. The device according to claim 4 wherein said first

electrode is fabricated from an active gas gettering material and said device functions as a getter type vacuum pump.

6. The device according to claim 5 wherein said first electrode is fabricated from a material selected from the group consisting of zirconium, titanium, beryllium, cerium, hafnium, aluminum, magnesium and tantalum.

7. The device according to claim 4 wherein said second electrode is a helical member.

8. The device according to claim 7 wherein said second electrode is hollow and adapted to sustain a flow of fluid coolant.

9. A triggerable electric arc discharge device comprising: a first electrode having an exterior surface and a bore therein extending adjacent said exterior surface and intersecting said exterior surface to define an opening in said exterior surface communicating with said bore; a trigger assembly including a trigger electrode with a portion thereof protruding from a ceramic body surrounding said trigger electrode, said assembly partially filling said bore so that there remains an unfilled portion of said bore and an unclosed portion of said opening communicating with said unfilled portion, said unfilled portion defining a trigger gap between the protruding trigger electrode portion surrounded by the ceramic body and the first electrode; a second electrode surrounding said exterior surface and spaced therefrom to define an arc gap which communicates with said trigger gap through said unclosed portion of said opening; means for supplying an arcing voltage between said first and second electrodes; means for supplying a pulsed trigger voltage to said trigger electrode; and, means hermetically enveloping at least portions of said first, second and trigger electrodes together with said arc and trigger gaps as well as the unclosed portion of said opening communicating said gaps, said means containing low pressure gas.

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