The present invention relates to the perforation of well walls by means of explosive perforating charges, more particularly to an improved method of perforating wells and also to a perforating gun of the expendable type which is so constructed that it may be lowered through a small diameter opening into a well and which indicates at the completion of the firing of a series of shots whether or not all of the cartridges in the gun were set off.

One of the methods now employed in completing a well drilled in the earth for purposes of producing oil, gas or other fluids or liquid minerals, is that of first lining the borehole with casing or pipe in order to prevent the walls of the hole from caving in and to preclude the entrance into the hole of undesired fluids from higher levels. In some cases, the hole is also cemented off at a level just below the desired producing zone. After these operations are completed, the casing is perforated by means of a perforating gun which is lowered into the casing to a position opposite the desired producing zone. When the perforating operation is completed, the gun is withdrawn from the hole and a string of small diameter pipe or tubing is run into the hole and is usually just above the producing zone. Water or thin mud is then pumped down the tubing and back out of the casing in order to wash out the heavy mud and thereby reduce the hydrostatic pressure at the bottom of the hole so that oil, gas, or other fluid or liquid mineral may flow into the casing through the perforations at the bottom of the hole. Another method of well completion is that of setting the casing into the hole, running a small diameter tubing into the casing, washing out the heavy drilling mud, sealing off the bottom end of the tubing at the desired point above the producing zone by using a packer or the like, and then perforating the casing opposite the producing zone. When this latter method is used it is evident that the perforating gun employed to perform the perforating operation must be of small diameter in order that it may be lowered through the small diameter tubing to a desired shooting position. A problem which is thus presented in the perforation of well walls after the tubing has been inserted therein is that of providing a perforating tool of sufficiently small diameter to pass through the tubing and which at the same time has a penetrating power and perforating efficiency substantially the same as the larger tools that are customarily used in similar boreholes in which tubing has not been set. It has been recognized that satisfactory perforation under such conditions may be accomplished by means of explosive perforating charges of the jet type which provide sufficient penetrating power while having an overall length which may be less than the diameter of the tubing. Since the effectiveness of the jet type charges is directly dependent upon the length thereof, it is desirable to employ cartridges having the maximum length which is compatible with their being lowered into the well through a small diameter pipe and exploded when at the desired depth. In one gun using jet type cartridges, the cartridges are lowered into the well through the tubing in a vertical condition of orientation and then tilted toward the horizontal after they are below the bottom of the tube. In another gun using jet type cartridges, a unitary elongated cartridge housing supports a plurality of cartridges which are disposed in a horizontal position as the gun is lowered into the well. It is obvious that the latter gun is less complicated than the former but that the former gun can accommodate cartridges having a longer length and thus greater penetrating power. With present day cartridges, however, satisfactory penetration may be effected with cartridges having a length slightly less than the internal diameter of the tubing through which the gun must be lowered.

Another problem which arises with the use of both of the above described prior art perforating guns is that of passing a relatively long gun through a tubing having slightly bowed or kinked areas. Since the length of the gun is determined by the number of charges carried thereby, this problem places a maximum limit on the number of shots or perforations which may be made at one time. Accordingly, it would be desirable to provide a perforating gun which may include sixty feet or more of charges and which, nevertheless, may be lowered through a tubing having an internal diameter only slightly greater than the outside diameter of the gun irrespective of the normal amount of bowing encountered in such tubing.

Another problem which arises because of the small diameter tubing through which the gun must be lowered into the well, is that of raising the gun to the surface after firing. It has been found that by utilizing a fragile cartridge carrier which is disintegrated when the cartridges explode, the remainder of the gun may be withdrawn from the well through the tubing without jamming. When, however, the cartridges in a fragile carrier are fired in the manner taught by the prior art for firing cartridges is a non-fragile carrier, the gun does not indicate how many, if any, of the cartridges are set off. In accordance with the prior art teachings the cartridges are sequentially fired from the top to the bottom. Consequently, should only the top cartridge fire, the remainder of the gun drops to the bottom of the well and no indication is provided as to whether or not all of the cartridges are fired. Therefore, it would be desirable to provide an indication after firing of the gun as to how many, if any, of the cartridges were fired and, therefore, whether or not the well casing is sufficiently perforated.

It is an object of the present invention, therefore, to provide an improved perforating gun having a sufficiently small diameter that it may be lowered through a narrow diameter tube which has been set in a well casing.

Another object of this invention is to provide a perforating device of small diameter that is partially expendable, and which after firing provides an indication on the non-expended portion thereof as to the number of perforations which were made in the wall of the well.

Still another object of the invention is to provide a perforating gun which is arranged to be severed at the time of firing from the supporting means by which it is positioned in the well.

A further object of the present invention is to provide a new and improved perforating device of the class described which includes means for assuring a high degree of disintegration of the device at the time of firing.

A still further object of the present invention is to provide a new and improved method of perforating well casings.

Another object of the present invention is to provide a new and improved method of perforating the walls of wells in which a small diameter tubing has been set.
Another object of the present invention is to provide a new and improved perforating gun which is of sufficiently small diameter to enable its being lowered through a tube set in a well casing, which is extremely flexible in use so as to enable adjustment of the number of perforations made in the casing per unit length, and which is provided with means for inserting near the top of the gun the number of charges set off during a preceding firing.

Briefly, the above and further objects may be achieved in accordance with the present invention by forming a flexible chain of explosive cartridges, linked together by frangible connections, lowering the chain into a well, there being perforated to the depth at which perforations are desired, and setting off successively adjacent ones of said explosive cartridges commencing with the one of said cartridges which is lowestmost in the well.

The invention, both as to its organization and method of operation, together with additional objects and advantages will be apparent from the following description taken in connection with the accompanying drawings, in which:

Fig. 1 illustrates a small diameter perforating gun characterized by the features of his invention shown in position in a cased borehole to perforate the well wall below a string of small diameter tubing that has been run and set above the zone to be perforated;

Fig. 2a is a view, partially in section, illustrating the upper portion of a preferred embodiment of a perforating gun incorporating the novel features of the present invention;

Fig. 2b is a view illustrating the lower portion of the same gun;

Fig. 3 is a view partly in section of a cartridge carrier and associated cartridge;

Fig. 4 is a view taken along the line 4—4 of Fig. 2a;

Fig. 5 is a fragmentary elevation showing the connection of a detonating cord to the non-expansible portion of the gun;

Fig. 6 is a view taken along the line 6—6 of Fig. 2a; and

Fig. 7 is an elevation of the lower portion of the gun.

Fig. 8 is a fragmentary view of an alternative embodiment of the cartridge carrier of the present invention; and

Fig. 9 is a fragmentary view of a gun of the present invention in which two strings of charges are separated by a predetermined distance.

Referring now to the drawings, and more particularly to Fig. 1 thereof, the present improved perforating gun, generally indicated by reference numeral 20, is therewith illustrated within a borehole 21 which has been drilled into the earth to a point below an oil bearing structure 22. As shown, the borehole 21 has been cased by casing or pipe 23 which has been run into the well and set, as by cementing or the like, to prevent the borehole from caving and to prevent water or other fluids from seeping into the bottom of the hole from the upper regions of the earth through which the hole 21 extends. Small diameter tubing 24 has also been run into the hole to extend from the earth's surface to a position just above the upper level of the production zone 22. As shown, the lower end 24c of the tube 24 has a bell-shaped configuration and has been sealed off by an annular packer 25 which effectively blocks fluid flow from the space between the casing 23 and the tubing 24 into the portion of the casing disposed below the lower end 24c of the tubing 24. As will be understood, however, that before the packer 25 is set, the heavy drilling mud which may have accumulated in the bottom of the hole is flushed out by pumping water or a light mud down the tubing 24 and back up the annular passageway between this tubing and the casing 23.

After the borehole has been cased and the tubing 24 set in the manner explained in the preceding paragraph, the perforating gun 20 must, of course, be lowered through the tubing 24 to a perforating position opposite the producing zone 22. This is conventionally accomplished by utilizing a steel sheathed cable 26 containing one or more electrically insulated conductors 30 that run the gun 20 into the borehole. To this end, the cable 26 is fixedly connected to the upper end of the gun 20 in a suitable manner, is passed over a sheave or measuring wheel 27 at the earth's surface and is unwound from a cable drum, all in accordance with conventional practice. Conventionally, the tubing 24 through which the gun 20 is lowered to its perforating position in the borehole has an internal diameter of approximately two inches. Jet-forming charges of the type which the present improved gun utilizes, conventionally have lengths slightly less than two inches so that these cartridges may be lowered through the tubing 24 in the normal horizontal position in which they are disposed when set off to perforate the walls of the well.

Referring now more particularly to Figs. 2a and 2b of the drawings, one embodiment of the present improved perforating gun is there illustrated as generally comprising a connector or housing 30 which is provided with suitable means (not shown) for attachment thereof to the lower end of the cable 26, an electric component housing 31, an extension sleeve and connector 32, and a somewhat flexible chain of charge or cartridge/carriers generally indicated by the reference numeral 33. The chain of cartridge carriers 33 consists of a plurality of identical cartridge carriers or holders 35 in each of which is mounted a jet type perforating cartridge 36, and a nose piece 37 which is suitably secured to the lowestmost one of the links 35. The leading end of the nose piece 37 is tapered so as to facilitate lowering of the gun 20 through the small diameter tubing 24. The cartridge carriers 35 and the nose piece 37 are formed of any suitable frangible material which will withstand the well pressure such, for example, as aluminum, plastic, ceramic, brass, cast iron or the like, so that when the associated or neighboring cartridge 36 explode these adjoining members are disintegrated and fall to the bottom of the borehole.

In order to set off the cartridges 36, a flexible detonating cord 38, which may be Primacord, or the like, is provided which extends from the top to the bottom of the gun and is operatively connected to the ignition portions of each of the cartridges 36. A suitable detonator 40 which may include a blasting cap is connected at one end to the nose piece 37 and at the other end to the cord 38. An insulating conductor 41, which is relatively flexible, is electrically connected between the detonator 40 and the top of the gun and is wrapped thereafter to prevent its being tangled or caught on the sides of the tubing 24 or the casing 23 as the gun is moved through the well. As is described in greater detail hereinafter, the conductor 41 is electrically connected with a conductor in the cable 26 so that an electric signal originating at the surface of the earth may be used to fire the detonator 40 and thus set off all of the charges in the gun. Because of the fact that the detonator 40 is located below the lowestmost cartridge 36, as detonation of the cord 38 progresses upwardly along the length thereof, first the lowestmost cartridge 36 is fired, then the next lowestmost cartridge, and so on until the top cartridge 36 has been fired. As a practical matter, the detonating cord may be defective or it may be blown out by an exploding cartridge before it has set off all of the cartridges 36 in the chain 33.

Since, in accordance with the present invention, the cartridges are set off from the bottom to the top of the cartridge string, when the gun 20 is withdrawn from the well after firing, if some of the cartridges 35 are still intact it is relatively easy matter to determine at what point detonation of the cord 38 stopped and, hence, the number of perforations that were actually made in
the well wall. In some instances one or more of the uppermost cartridges may have been detonated but are knocked off in pulling the gun back up through the narrow tubing 24. However, in accordance with a further feature of the present invention there is provided means for indicating when the entire length of the cord 30 has been detonated so as to provide a positive indication that all of the cartridges were actually fired in the well, as will be described in more detail hereinafter.

Considering the perforating gun 20 of the present invention in greater detail, Fig. 2a illustrates the connector 30 as being connected to the housing 31 by means of a plug and socket joint, an axial end 44 of the connector 30 being received in, and machine screwed to the upper portion of the housing 31. Seepage of well fluids into the housing 31 through the joint is prevented by a seal which comprises a pair of resilient O rings 45 and 46 mounted in spatially arranged annular grooves 47 and 48 in the end 44 of the connector 30. The lower end of the housing 31 is connected to an adapter 49 by means of a similar plug and socket joint including an axial plug 49a on the adapter 49, and a seal between the two elements is effected by a pair of resilient O rings 51 mounted in suitable annular grooves in the pin 49a.

In accordance with conventional practice, the portion of the ignition circuit which is within the housing 31 comprises a conductor 54, a resistor and fuse assembly 55 and a conductor 56 which are serially connected to transmit an ignition signal from the cable 26 to the detonator 40. Although not shown in the drawings, it will be understood by those skilled in the art that one of the conductors in the cable 26 is electrically connected to the conductor 54 by suitable means. Because of the deleterious effect of well fluids on the electric components mounted in the housing 31, and because of the high pressure encountered in wells, a fluid tight sealed connection, which is effective at high pressures, is provided for connecting the conductor 41 to the conductor 56. Briefly, the conductor 56 is secured to a contact nut 58 which is threadedly engaged with the upper end of a pressure pin 62 which extends through a central bore 66 in the adapter 49. The pin 62 is electrically conductive and threadedly attached to a terminal member 64 which may be electrically connected to the conductor 41, and the connection is sealed off from the surroundings by means of an elastic plug cap 70 which is staked over the adjoining portions of the terminal 64, the pin 62 and the conductor 49. Although the adapter 49 might be constructed of an insulating material it is preferable for it to be constructed of cast iron or steel, and, therefore, it must be insulated from the pin 62. Accordingly, an insulating sleeve 63 is disposed between the rod-like portion of the pin 62 and the wall of the bore 66, and the bore 66 is enlarged at its upper end so as to provide an air space between the sides of the nut 58 and the adapter 49. Additionally, a pair of insulating washers or packers 58a and 67 are respectively interposed between the lower face of the nut 58 and the adapter 49 and between the shoulder on the enlarged end of the pin 62 and the adapter 49.

As shown, the external diameters of the adjacent sections of the pin 62 and the terminal 64 are substantially equal to the diameter of an apertured central boss 68 on the bottom face of the adapter 49. Annular recesses 69a are provided in each of the members near the adjoining portions thereof and transverse sections of the cap 70 are pressed therein by means of suitable wires 69a which are tightly wrapped around the cap 70 opposite the underlying recesses. Also, the lower portion of the cap 70 is stretched over a short length of a sleeve 71 which envelopes a spliced joint between the conductor 72 and the terminal 64. The conductor 72 is connected to the conductor 41 by means of a conventional spliced and soldered joint 72a.

For the purpose of protecting these electrical connections from damage and also for attaching the chain 33 to the remainder of the gun 20, there is provided the sleeve 32 which has a plurality of apertures 73 for minimizing the pressure differential across the well wall. The upper end of the sleeve 32 is threadedly attached to the adapter 49 and the lower end is attached to the chain 33 by means of a link adapter 74. As shown, the link adapter or reducer 74 is connected by pin and socket joints to both the sleeve 32 and the uppermost carrier 35 in the chain 33 but it will be understood that any other suitable type joints may be provided.

In accordance with the present invention, the link adapter 74 is provided with a central bore 75 and a branch bore 76 which communicates with the bore 75 near the upper end thereof to provide an opening through which the conductor 41 may be threaded for connection to the conductor 72. The lower portion of the bore 75 provides a socket into which a stud 77 of the uppermost carrier 35 is inserted and the carrier 35 is attached thereto by means of suitable machine screws.

Referring to Fig. 3, each cartridge carrier 35 comprises, in addition to the stud 77, an annular body portion 78 defining a central recess 35a and a tubular portion 79 which protrudes from the body portion 78 in a direction diametrically opposite from the stud 77. A dowel receiving transverse hole 75a is provided in the stud 77 and a similar hole (not visible in the drawings) is provided in the tubular portion 79, the principal axis of these holes being offset from one another by sixty degrees. Consequently, when linked together in a chain the faces of the cartridge carriers 35 spiral about the chain at a cartridge-to-cartridge angle of sixty degrees.

In accordance with an important aspect of the present invention, the external diameter of the stud 77 is less than the internal diameter of the mating tubular portion 79 so that when a plurality of carriers 35 are connected together to form a chain 33, a loose fit is provided between adjacent carriers and the overall gun is somewhat flexible throughout its length. Consequently, the gun 20 may easily be lowered into the well through the narrow tubing 24 without jarring even though the tubing is kinked or bent at certain points along its length. As shown, peened over dowel pins 80 may be used to secure adjacent carriers 35 together, but any other suitable means such, for example, as cotter pins, may be used for this purpose.

Referring now to Fig. 4, there is shown in cross section, a jet type cartridge 36 mounted in a cartridge carrier 35. Briefly, the cartridge 36 consists of a case 82 having an explosive charge carrying chamber 83, in which is closed by means of a cap 84 which is press fitted over the end 82a of the case 82. A rabbet 85 surrounds the open end of the cap 84 for coaction with a resilient sealing ring 86 to seal off the chamber 83. As shown, a thin cone shaped liner 83a is disposed within the chamber 83 to form a conical cavity in the end of the explosive charge within the chamber, so that when the charge explodes, the well known explosive jet is formed which disintegrates the liner 83a and the cap 84 and penetrates the casing 23 and the well wall. In addition, however, the case 82 and the carrier 35 are completely disintegrated or broken into small pieces which fall to the bottom of the well.

For the purpose of facilitating the connection of the detonating cord 38 to each cartridge 36 so that the cord 38 is held in place and protected from damage until detonated, and then, when detonated, sets off each of the cartridges 36, a hole 86 is provided in each case 82 in proximity to the chamber 83. The diameter of the hole 86 is slightly larger than the diameter of the detonating cord 38, and a wall 87 which separates the chamber 83 from the portion of the cord 38 disposed in the hole 86 is provided which is relatively thin and is ruptured so as to
detonate the explosive material in the booster cavity of the chamber 83 as the cord 38 is detonated.

The cartridges 36 are securely mounted in the respective carriers 35 by insertion of the cases 82 into the aperture 35a until the annular flanges 88 on the cases abut the faces of the associated portions of the cases 82, when the cartridges are so mounted as the cartridges 36 are disintegrated or blown into relatively small pieces which fall to the bottom of the well.

In order to set off the cartridges in the order in which they are lowered into the hole, thereby to achieve the advantages set forth above, the cord 38 is threaded through the holes 86 in all of the cartridges 36, and the lower end thereof is operatively connected to the detonator 40 which may be conveniently mounted on the nose piece 37. The upper end of the cord 38 is clamped to the adapter 74 by means of a clamp 89 which is received in an annular groove 96 in the adapter 74. An integral component of the cord 38 with respect to the gun 20 is thus prevented. Moreover, inasmuch as the cord 38 is threaded through the cartridges 36 which are mounted in a spiral along the chain 33 the cord is held within the external diameter of the gun 20 and does not rub against the tubing 21 as the gun is lowered into the well. As shown in Figs. 1 and 2b, the conductor 41 is wrapped around the cord 38 to prevent its becoming separated from the gun 20 as it is lowered into the well.

Referring particularly to Fig. 7 it may be seen that the nose piece 37 is attached to the lowermost carrier 35 through the medium of a spacer sleeve 98 so as to provide a place for mounting the detonator 40 within the overall external diameter of the cartridges 36. The detonator 40 is conventional and includes a pair of lead wires 92 and 93 across which a firing potential is applied in order to fire the detonator 40 and thus detonate the cord 38. One of the wires 92 is relatively short, having a length of about one-half inch, and may thus be secured to the flange 91 of the nose piece 37 so as physically to secure the lower end of the detonator 40 to the gun 20 and also to connect it to ground. The other conductor 93 is connected through a milivolt spliced connection 94 to the conductor 41. Therefore, when a firing signal in the form of a voltage is impressed upon the conductor 41, the detonator 40 is fired to in turn detonate the cord 38 which rapidly detonates to the top of the chain 33 sequentially setting off the cartridges. If the cord 38 is detonated throughout its entire length the upper end thereof breaks the clamp 89 so that when the gun is withdrawn from the well a positive indication is provided that all of the cartridges in the gun have been actually fired and not just broken off in withdrawing the gun. While the band 89 provides a convenient means for physically indicating the complete detonation of the cord 38, it will be obvious that any other suitable means may be employed to provide such indication.

It may be seen that the distance between the hole 77a and the length of the carrier 35 is determinative of the number of cartridges 36 per unit length in the chain 33. Therefore, in accordance with the present invention, and as shown in Fig. 8, the stud 77 may be provided with a plurality of spatially arranged holes 77a so that when assembling the gun in the field variations may be had in the number of perforations per unit length. Moreover and as shown in Fig. 9, a spacer bar 96 may be used to separate charge carrying portions of the perforating gun thereby to permit perforation of the well in two or more widely separated areas during a single firing operation.

Although the manner in which the improved perforating gun 20 is used to perforate a well in accordance with the teachings of this invention will be clear to those skilled in the art from the above description, considered briefly, the cartridges 36 are first mounted in respective carrier cartridges 35 which may be joined together in the field to form the chain 33. The nose piece 37 and the adapter 74 are then attached to opposite ends of the chain. The upper portions of the gun having been preassembled in an obvious manner, the conductor 41 is then threaded through the hole 76 in the adapter 74 and joined to 72. Following this, the extension sleeve 32 is threaded onto the adapter 49 over the electric connection and the adapter 74 is pinned to the sleeve 32. The ignition cord 38 to which the detonator 40 may or may not have been previously assembled is then threaded through the holes 86 in the cartridges 36 and a cover 38b is placed over the end thereof before clamping to the adapter 74. Consequently, the clamp 89 not only secures the cord 38 to the gun 20 but in addition prevents the cord cover 38b from tearing loose as well as providing the above described indication of complete detonation. Next, the conductor 41 is wrapped around the cord 38 as shown in Fig. 2b, and connected to the conductor 93 by the joint 94. At this time the conductor 92 may be attached to the nose piece 37 to complete the gun.

After the gun has been assembled it is lowered into the tubing 24 by the cable 26 until the chain 33 is in place. A firing voltage is impressed upon the proper conductor in the cable 26 which fires the detonator 40 to set off the cartridges 36. Upon completion of the firing or perforating operation, the gun 20 is withdrawn from the well. If the clamp 89 has been broken or disintegrated, a positive indication is given that the cord 38 has been detonated throughout its effective length and that all of the cartridges 36 were set off. On the other hand, if a few carriers 35 remain intact because, for example, of a failure of the cord 38, the number of cartridges which were set off is apparent.

It may be seen that the present invention enables the efficient perforation of well casings in which a narrow tubing has been set by facilitating the lowering of long lengths of charges through the tubing and by providing, at the completion of the firing operation, a positive indication of the number of cartridges which were set off. While the invention has been described by a particular embodiment thereof, it will be understood by those skilled in the art that many changes and modifications may be made without departing from the invention. Therefore, in the appended claims it is intended to cover all such changes and modifications as fall within the true spirit and scope of the invention.

What is claimed as new and desired to be secured by Letters Patent of the United States is:

1. A device for perforating a well casing, comprising, in combination: a retrievable, relatively indestructible gun; an elongated expendable fragile chain of cartridge links respectively carrying jet-forming explosive perforating cartridges secured to said gun and depending therefrom, said chain having a predetermined degree of flexibility adapting the device to be readily lowered through a string of tubing having an inside diameter only slightly larger than the outside diameter of the cartridges without jamming due to kinks in the tubing, connecting means to form a chain of cartridge links with the jet axis of each cartridge carried thereon facing the well casing at a desired phase angle relative to the jet axis of an adjacent cartridge, said connecting means including a stud and a tubular member respectively extending from opposite ends of each cartridge link, each of said tubular members being adapted to interfittingly receive the stud of an adjacent cartridge link, the inside diameter of the respective tubular members having a predetermined size relationship to the outside diameter of the respective studs adapted to permit a desired degree of relative movement between ad-
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jacent cartridge links, a pin-receiving bore respectively extending transversely through each of said studs and each of said tubular members, the principal axis of the stud bore and the tubular member bore of each cartridge link having an angular relationship to each other and to the link’s cartridge jet axis adapted to provide a desired phase angle between the jet axes of adjacent cartridges when they are connected together by interfitting adjacent stud and tubular members with their respective bores in alignment, a plurality of pins for fastening adjacent cartridge links together respectively loosely received in the aligned bores of each interfitted stud and tubular member; a flexible detonating cord operatively interconnecting said cartridges; clamping means fixedly secured to said gun, said clamping means attaching said cord to said gun with the upper end of said cord positioned in proximity to said clamping means so as to fracture said clamping means when ignited; and means for initially igniting said cord at the lower end thereof to effect bottom firing of the device, whereby the fracturing of said clamping means provides a positive indication that said cord has been ignited throughout its length.

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2. A device according to claim 1 in which said clamping means is received in an annular recess in said gun to prevent it from being torn from the gun during withdrawal of the latter from a well.

3. A device according to claim 1 in which the respective studs have at least two longitudinally spaced pin-receiving bores whereby the respective studs and tubular members may be fastened together by inserting the respective pins in selected ones of said stud bores to provide a desired longitudinal spacing between the jet axes of adjacent cartridges.

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