SEALING DEVICE FOR PERFORATED WELL CASING

Original Filed April 21, 1964 4 Sheets-Sheet 1

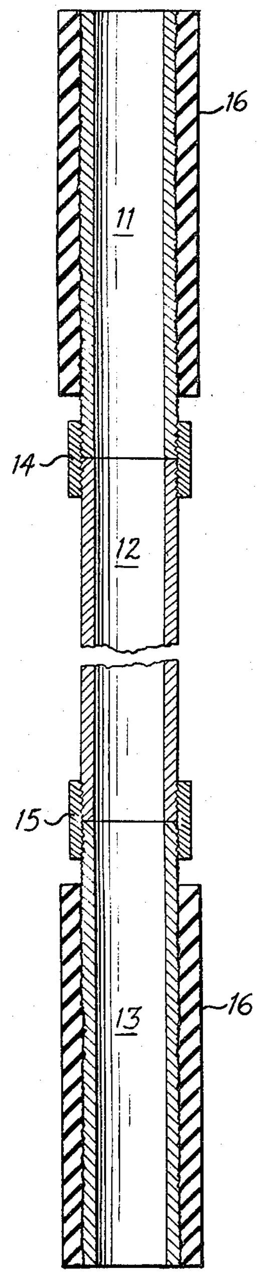

Fig. 1

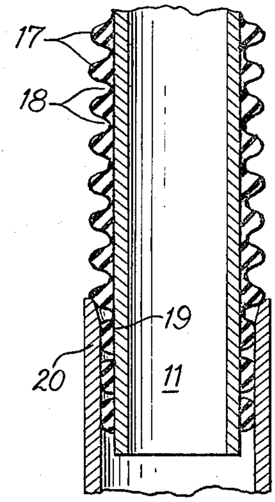

Fig. 2

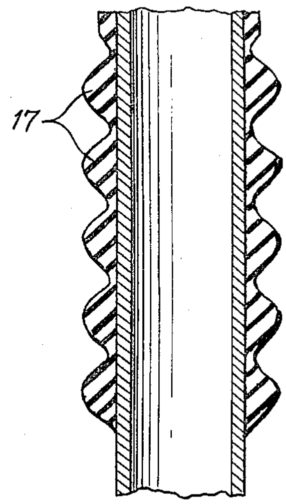

Fig. 3

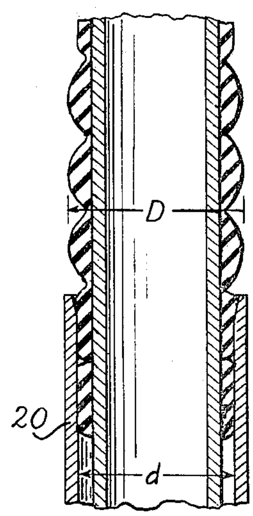

Fig. 4

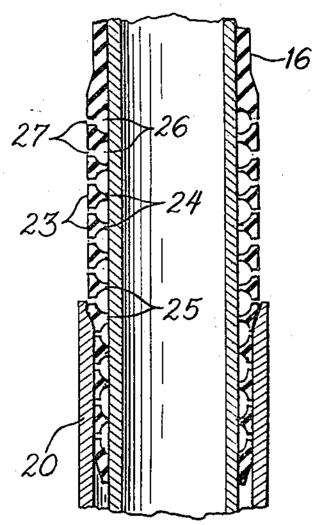

Fig. 8

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SEALING DEVICE FOR PERFORATED WELL CASING

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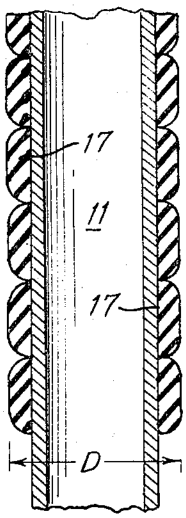

Fig. 5

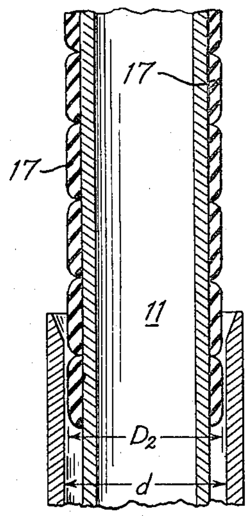

Fig. 6

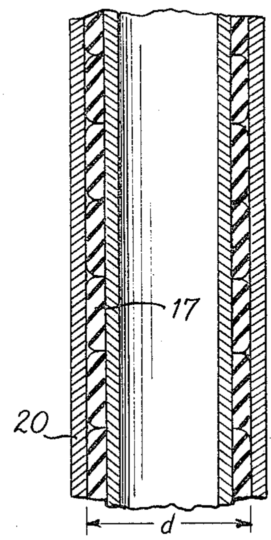

Fig. 7

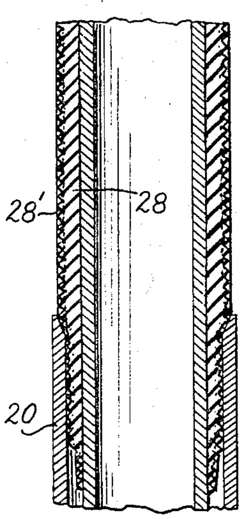

Fig. 9

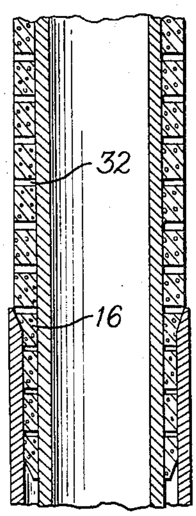

Fig. 10

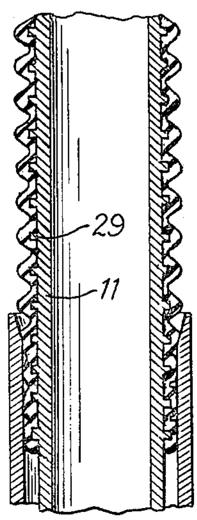

Fig. 11

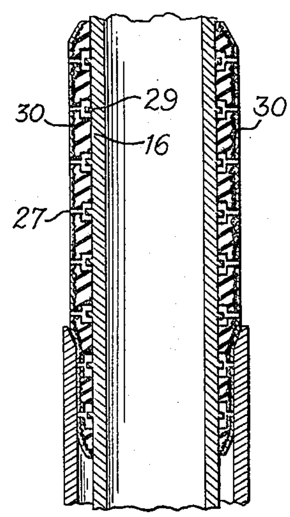

Fig. 12

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SEALING DEVICE FOR PERFORATED WELL CASING

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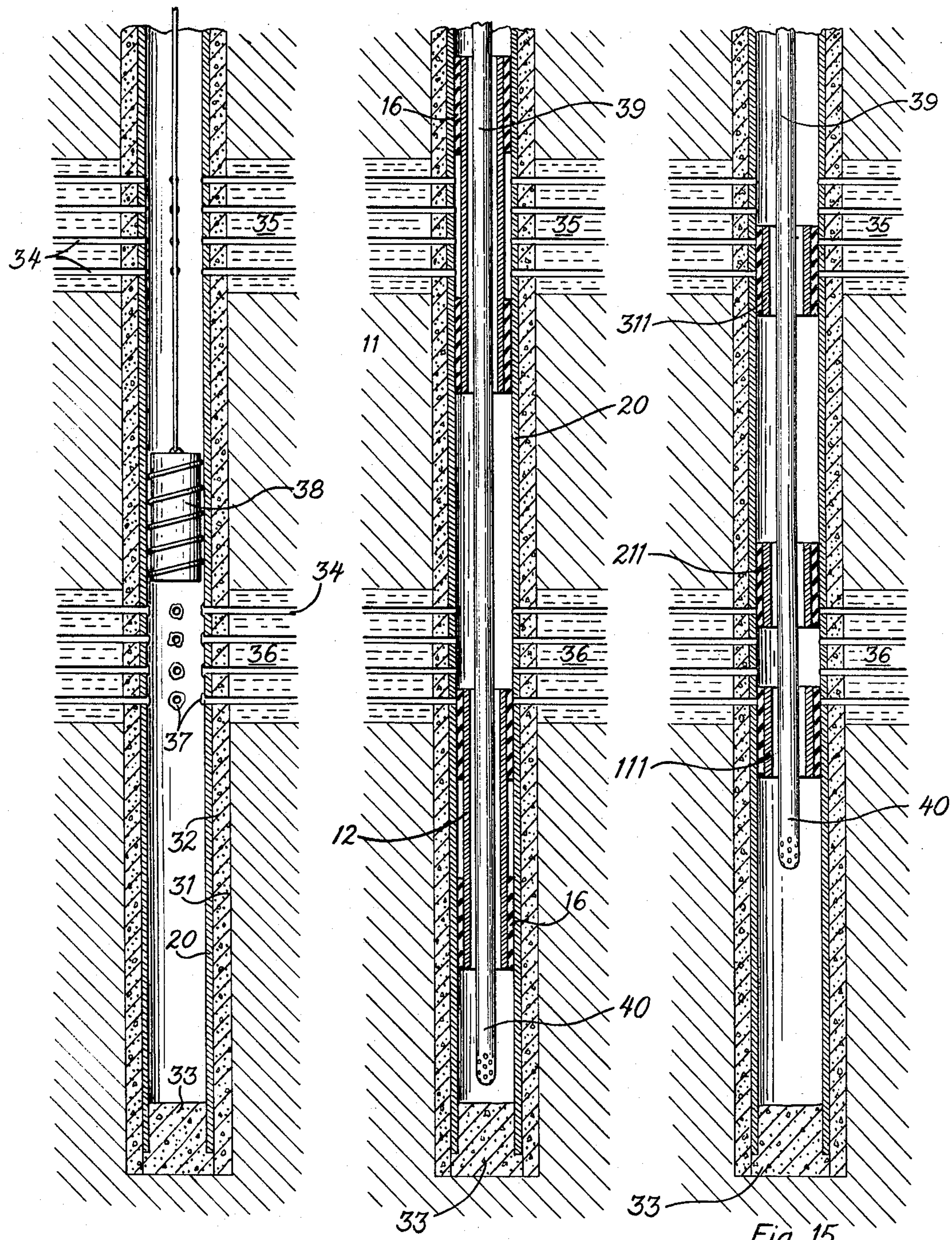

Fig. 13 Fig. 14 Fig. 15

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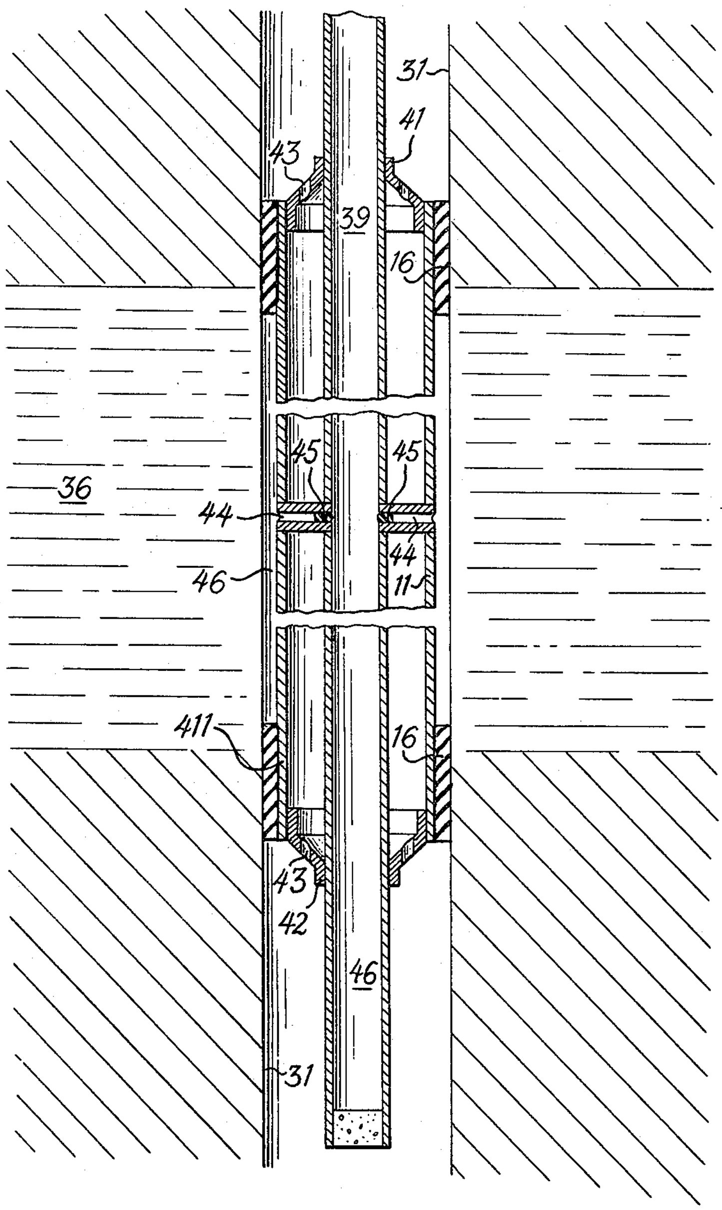

Fig. 16

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United States Patent Office 3,385,367
Patented May 28, 1968

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3,385,367
SEALING DEVICE FOR PERFORATED WELL CASING

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Continuation of abandoned application Ser. No. 361,327, Apr. 21, 1964. This application Dec. 7, 1966, Ser. No. 609,974
3 Claims. (Cl. 166—191)

ABSTRACT OF THE DISCLOSURE

The present improvements provide a sealing element for wells in which a casing is installed. The sealing element comprises a central tubular core and an outer covering of elastomer material of a relaxed diameter larger than the internal diameter of the casing. The covering comprises spaced annular ribs and is inserted, together with its central sleeve, into the casing in compressed condition and after presoaking in a hydrocarbon liquid. The liquid forms a lubricating film during insertion and during subsequent movement of the element relatively to perforations of the casing in order to open and seal such perforations.

This application is a continuation of my copending application Ser. No. 361,327, filed Apr. 21, 1964, now abandoned.

The invention deals with the problem of controlling the flow of fluids into a perforated well casing. The perforations may be present at a single level or formation or at several different levels or formations. They extend through the casing wall and through the surrounding cement layer or sheath into the adjacent formation, thus opening up the formation by explosion-produced passages leading from the formation into the well casing.

The control may involve the temporary or permanent sealing of all the perforations at a certain level, while initiating or maintaining flow at a different level, or it may involve the selective control of the fluid flow at a particular level for the purpose, for example, of reducing gas flow through the higher perforation of the zone or level, or reducing water flow through the lower perforations of the zone or level by selective closing or restriction of such upper or lower perforations.

The invention accomplishes this in a manner in which the inner diameter of the casing is not excessively reduced, so that a production string, including a pump, may extend therethrough, and further in such a manner that the flow may subsequently be adjusted by opening or closing the perforations at one level and independently adjusting the flow through the perforations of a different level above or below the one level.

It is known to seal the perforations of a zone by a procedure called "squeeze cementing." This involves the installation of packers below and above the zone to be cemented, the injection of cement through the perforations into the formation, followed by removal of the packers and of cement remaining in the casing. The result is the permanent closure of the perforations.

Another known practice involves the installation of a straddle tool comprising essentially a piece of tubing with a mechanically or hydraulically expansible packer at each end, thus straddling the perforations which lie between the packers. The conventional straddle tools have a relatively small central bore which severely restricts treatment of a zone, or production from a zone, below the tool through the bore of the tool.

Further, the expansible packers which form a part of the straddle tool exert high specific pressures of the order of 1,500 to 10,000 p.s.i. against the casing well which

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only a sound and noncorroded casing can withstand. By way of contrast the invention employs sealing pressures of a different order of magnitude. Pressures of less than 300 p.s.i. were found to be sufficient for a reliable seal.

The invention involves the installation of a valve sleeve within the casing. The valve sleeve comprises essentially a central tubular metal sleeve body providing a large central passage through which well fluids may flow, through which a production string including a pump may extend, or through which appropriate tools may reach in order to act on and reset a similar valve sleeve installed at a lower zone or level.

The metal sleeve body is tubular and rigid in contrast to the known casing patches which are inserted into a damaged well casing in a corrugated state in which their outer diameter is reduced, and which are subsequently mechanically expanded into tubular or near-tubular shape by flattening out of the corrugations.

The metal sleeve body has an outer covering of elastomer material bonded thereto which, in installed condition, is sufficiently compressed to produce a seal between sleeve and casing. Even though the specific sealing pressure exerted against the casing is of a low order, a reliable seal against high pressures is readily produced by an elastomer body of appropriate length.

The elastomer covering may be composed of solid or of porous elastomer material. Elastomer materials, as such, may, for the purpose of the present invention, be divided into those which remain substantially unaffected by contact with hydrophobic liquids and those which, upon exposure to hydrophobic liquids, exhibit an appreciable degree of swelling.

In all applications according to the invention the purpose of the elastomer covering is to produce a seal resulting from compressive force exerted by the exterior element, such as the well casing or the well bore, upon the elastomer or, conversely, by the force with which the elastomer expands against the exterior element, the casing or well bore.

For this purpose the elastomer body may be compressed prior or incidental to the installation, such as its insertion into the well casing. In order to facilitate insertion or produce a tighter seal, the elastomer may be precompressed with or without the simultaneous application of heat to reduce its original relaxed diameter by a "set."

In place of, or in addition to, such compression or precompression, sealing force may be generated by swelling of the elastomer seal which is then made of a material which upon contact with a hydrophobic liquid causes the sealing body to swell.

Experiments conducted in connection with the invention showed that particularly high degrees of swelling can be produced if the elastomer orignally contains a substantial amount of a plasticizer which is then extractable, for example by leaching in a solvent and subsequent evaporation of the solvent. The elastomer shrinks under such treatment and exhibits a remarkable degree of swelling in relation to its shrunken dimensions when exposed to a hydrophobic liquid. At the same time a remarkable degree of its original tensile strength is retained.

Instead of being of solid composition or construction the elastomer may be manufactured as a porous or spongelike body with or without an exterior skin which is denser than the interior, or may be mechanically reinforced.

Such porous or spongelike elastomer bodies may, again, be made of materials which exhibit little swelling when exposed to hydrophobic liquids or of those which swell appreciably under such conditions, depending on the particular requirements.

Elastomer seals may even be made water swellable.

For this purpose a water swellable gel may be introduced into the pores of a porous body which, in itself, may be oil swellable. Drying of the gel produces shrinkage of the gel filled pores. The gel subsequently expands when exposed to water. Such water swellability can therefore be imparted even to an elastomer which by itself is swellable in hydrocarbon liquids, thus superimposing the phenomena of water swelling upon oil swelling.

The valve sleeve is inserted into the casing and is pushed down, for example by an appropriate cable-suspended weight or tubing string to the desired location at which it either seals, partially seals, or clears the perforated zone.

Subsequently the valve sleeve is readily moved either by moving it down further or lifting it to the desired adjusted position in which it clears or seals the perforated zone, or to a zone above or below or in which it uncovers certain perforations of the same zone in which the valve sleeve was originally set.

In all instances the valve sleeve forms a sleeve valve with the casing which is preferably suitably prepared by removing any burrs from the perforated zone or zones, for example by a conventional reaming tool.

Tests have shown that the valve sleeve may be moved in compressed condition from the point of insertion at the top of the casing along very substantial lengths of casing without any appreciable wear of the elastomer covering by either the casing wall or the joints of the casing.

A swellable valve sleeve lowered to the desired level and maintained suspended for a sufficient time swells and seats itself tightly. This can be accomplished within 6 to 12 hours from the time of insertion of the valve sleeve into the casing or well bore.

Summary of the invention

The invention employs in a well comprising a perforated casing a sealing element comprising a central annular core and an outer core covering of elastomer material shaped to form annular ribs leaving void spaces between such ribs, the sealing element being inserted into the casing in compressed condition and after presoaking in a hydrocarbon liquid which provides a lubricating film during the initial insertion and during subsequent movement of the sealing element with respect to the perforations to seal or open the same.

The various features and advantages of this invention will appear more fully from the detailed description which follows accompanied by drawings showing, for the purpose of illustration, preferred embodiments of the invention. The invention also resides in certain new and original features of construction and combination of elements, as well as steps and sequences of steps hereinafter set forth and claimed.

Although the characteristic features of the invention which are believed to be novel will be particularly pointed out in the claims appended hereto, the invention itself, and the manner in which it may be carried out may be better understood by referring to the following description taken in connection with the accompanying drawings forming a part of it in which:

FIG. 1 is an elevational section through a valve sleeve according to this invention;

FIGS. 2 to 12 illustrate, in elevational section, views of specific forms of elastomer coatings:

FIG. 13 is a diagrammatic and simplified vertical section of a well and casing being prepared for the installation of a valve sleeve;

FIGS. 14 and 15 are corresponding illustrations of the well and casing with valve sleeves installed therein in different positions; and

FIG. 16 is a diagrammatic illustration of a straddle sleeve whose elastomer seals seal against the well bore.

In the following description and in the claims various details will be identified by specific names for convenience. The names, however, are intended to be generic in their application. Corresponding reference numerals refer to corresponding parts in the several figures of the drawings.

The drawings accompanying, and forming part of, this specification disclose certain specific details of the invention for the purpose of explanation of broader aspects of the invention, but it is understood that details may be modified in various respects without departure from the principles of the invention and that the invention may be applied to other structures than specifically shown.

The valve sleeve of FIG. 1 comprises three peripherally rigid tubular sections **11**, **12** and **13** connected by threaded couplings **14** and **15**. The exterior surface of sections **11** and **13** is roughened by sandblasting or knurling to provide a secure grip for an elastomer covering generally indicated at **16** and bonded to the surface. The contour of the elastomer covering may vary in form, representative forms being shown in FIGS. 2 to 12.

There are different elastomer materials in existence and commercially available. These will be described collectively further below. At this point it is sufficient to state that the covering may either consist of solid or of open-pore spongelike elastomer material, or solid elastomer material which may be shaped to provide voids into which the material can be deformed when the elastomer material is in a state of compression inside the casing in order to produce the desired seal with respect to the casing.

The valve sleeve shown in FIG. 1 may be of considerable length of the order of 10 to 30 feet or more, depending on the length of the central section **12** which is chosen to meet the particular local requirement. A representative practical length of the end sections is 4 feet.

As shown in FIG. 2, the tubular elastomer covering may be shaped as a series of annular ribs **17** preferably of solid material spaced from one another by annular valleys **18**. The outer diameter D of the ribs or rings **17** exceeds the internal diameter d of the casing **20**. By the act of insertion the annular ribs are deformed in profile, as a result of which the space or volume of the annular valleys **18** is reduced. The elastomer rings **17** may be manufactured as one piece comprising a plurality of annuli **17**.

This multi-ring piece may either be directly molded on the sleeve, or it may be premanufactured and then bonded to the sleeve. The rings **17** may also be premanufactured as individual rings and then bonded to the outer surface **19** of the rigid tubular sleeve member **11**.

The elastomer structure shown in FIG. 3 represents the relaxed state of the rings **17** which are substantially of saw-tooth or gable shape appearance in cross section. This structure is then precompressed to a reduced diameter and maintained in the precompressed state under application of heat for a time to produce a set. The elastomer body then has the appearance as shown in the upper portion of FIG. 4, its relaxed but set diameter being D which is subsequently reduced to d by insertion into the casing **20**.

The elastomer sleeve shown in FIG. 6 may be made from oil or water swellable elastic material capable of swelling within the casing upon contact with a swelling liquid, e.g., crude oil or water, respectively, to form a tight seal as shown in FIG. 7.

The elastomer sleeve shown in FIG. 5 is constructed from a material containing a substantial proportion of a plasticizer. The relaxed diameter D_1 of the rings **17** is reduced to a lesser diameter D_2 indicated in FIG. 6 as a result of shrinkage of the elastomer by extraction of the plasticizer. The reduced diameter D_2 may be smaller than the diameter d of the casing **20** into which the sleeve **17**, **11** is to be inserted.

After insertion into the casing the elastomer seal is exposed to a swelling liquid, for example crude oil to which gasoline may be added, causing the sleeve to expand to such a degree that the required sealing pressure is developed. The expanded sleeve **11**, **17** is shown in its swelled, expanded condition in FIG. 7.

In the form of valve sleeve shown in FIG. 8 the elastomer component is essentially a thin walled piece of tubing 23 having integral internal annular ribs 24 which are bonded to the sleeve exterior 11 along their respective base surfaces at 25. This arrangement results in the formation of a series of annular chambers 26 vented to the periphery by vent passages 27.

As the valve sleeve is being inserted into the casing 20, the elastomer sleeve or tubing 23 is being compressed, thereby reducing the size of the chambers 26. This particular form of valve sleeve encounters somewhat less resistance at casing joints when it is being moved to its eventual location which may involve travel of the order of a mile.

The open-pore sponge body 28 of the elastomer material shown in FIG. 9 has a dense tough outer porous skin 28', the end of which is directly bonded to the sleeve 11 at 30. Insertion of the valve sleeve into the casing 20 results in compression of the sponge body 28 which becomes correspondingly denser.

The elastomer sleeve 16 of the valve sleeve shown in FIG. 10 consists of open-pored elastomer sponge material containing in its pores a liquid swellable gel. Substantially radial passages 32 are formed in the sponge body whose volume is subsequently reduced by compression of the elastomer body incidental to its insertion into the casing 20 of smaller diameter. If the swellable substance in the pores is a water swellable gel, the swelling force thus produced is superimposed upon the elastic force of the elastomer.

Instead of bonding the elastomer layer to the sleeve 11 the sleeve may be provided with peripheral ridges or flanges 29 which interlock with correspondng grooves of the elastomer body as shown in FIG. 11. The tightness of interengagement increases when the valve sleeve is inserted into the casing, thereby compressing the sleeve.

In the form shown in FIG. 12 the elastomer body has a certain limited degree of freedom to move axially with respect to the metal sleeve 11. The interior spaces 26 into which the ridges 29 extend are vented by passages 27. The elastomer body is reinforced peripherally by a suitable cord or fabric layer 30. Such reinforcing layers are preferably so constructed as to limit axial expansion while permitting radial expansion.

FIG. 13 is a diagrammatic representation of a well comprising a casing 20 within the well bore 31 and a layer 32 of cement between bore and casing. The bottom of the casing is sealed by a cement plug 33.

Perforations 34 extend through the casing wall 20 and the cement 32 into the surrounding oil bearing formations 35 and 36. The perforating procedure produces burrs 37 which are removable in a known manner by a casing scraper or reamer diagrammatically indicated at 38.

In the arrangement illustrated in FIG. 14 the upper formation 35 is temporarily, although not necessarily permanently, sealed by a straddle sleeve of the type shown in FIG. 1. One elastomer body seals the valve sleeve relatively to the casing 20 above the formation 35 and another elastomer body seals the valve sleeve relatively to the casing 20 below the formation 35. This form of seal permits substantial tolerances in the placement of the valve sleeve with respect to the perforations.

A production string extends through the upper valve sleeve in formation 35 and through a lower valve sleeve in formation 36, the pump 40 being at the end of the string.

In this diagrammatic illustration wall thicknesses, elastomer thickness and valve sleeve thickness are exaggerated for the sake of clarity. Correspondingly the diameter of the central passage through the valve sleeves appears too small. It is considerably larger in actual construction. For example, a casing having an internal diameter of 4" accommodates a valve sleeve having an internal passage diameter of 3⅜".

The lower valve sleeve of FIG. 14 is set to close the

lower zone of the perforations of the formation 36 to reduce the flow of liquid, for example water, therethrough.

Subsequently the lower valve sleeve may be raised to seal the lower formation 36 to a greater degree, or completely, while the upper valve sleeve may be moved to expose a portion, or all, of the perforations within formation 35.

In the arrangement shown in FIG. 15 three relatively short valve sleeves, 111, 211 and 311 are so set that the central perforations within the lower formation 36 are exposed, while the upper and lower zones of the same formation are sealed by valve sleeves 211 and 111, respectively. At a later period the lower formation may be sealed completely by moving the valve sleeves 111 and 211 into contact with each other.

The valve sleeve 311 is so set with respect to the perforations of the upper formation 35 as to restrict production through the upper portion of the perforated zone only.

Each one of the these valve sleeves may readily be moved by gripping it by means of a conventional tubing anchor. This type of tool is in essence an expansible mandrel or core which is lowered into the well and expanded by rotation in one direction, generally counterclockwise or left-handed rotation, and is contracted by rotation in the opposite sense, usually clockwise or right-handed rotation.

The force exerted by such gripping tools is sufficient to permit exertion of great force, either pulling or pushing, on the valve sleeve in order to move it to the desired new location.

For the purpose of adjusting valve sleeves conventional bumping tools may also be employed to move the valve sleeve by impact rather than static force. The use of bumping tools is particularly advantageous where the desired displacement of the valve sleeve is relatively small, but where accurate positioning is required.

Valve sleeves were constructed of steel tubing having an outer diameter of 3⅝" and an internal diameter of 3⅜" and a total length of 48". Elastomer layers were bonded or vulcanized to the sandblasted outer surface of the tubing. The valve sleeves were then inserted for testing in standard 4½" casing having an internal diameter of 4".

Test 1.—The elastomer covering had the shape shown in FIG. 2 composed of individual rings of ¼" width and an external diameter of 4⅛" of neoprene rubber cured with benzoyl peroxide and having a hardness of 40 durometer units.

The valve sleeve was soaked in crude oil, pressed into the casing and subjected to a differential pressure of 3000 p.s.i. across the entire length of the sleeve. There was no leakage.

Thereafter a sub-assembly of only six rings was subjected to differential pressure. This latter test established that six rings provided a tight seal up to 520 p.s.i.

Test 2.—An elastomer covering was applied to the valve sleeve core in the form shown in FIG. 5 composed of individual rings of a width of ½" and an outer diameter of 4³⁄₁₆". The rings consisted of "Nordel" rubber cured with benzoyl peroxide and containing 25 percent plasticizer by volume. "Nordel" rubber, as hereinafter specified, is an ethylene propylene hydrocarbon rubber cured with benzoyl peroxide.

The valve sleeve was then pressed into casing tubing and maintained at a temperature of 240° F. for 48 hours. After removal of the valve sleeve from the 4" tubing the elastomer coating had acquired a set, its external diameter being 4⅛".

The valve sleeve was then soaked in crude oil and inserted into the casing. Subjected to a differential pressure of 3000 p.s.i. it maintained a tight seal.

A sub-assembly of six rings maintained a tight seal up to a differential pressure of 550 p.s.i.

The force required to insert the valve sleeve into the casing and to move the valve sleeve axially within the casing was considerably less than in Test 1. This appears to be due to limited absorption of crude oil by the rubber rings, which oil then acts as a lubricant.

Test 3.—A neoprene sleeve was bonded to the valve sleeve core. The neoprene sleeve had the shape shown in FIG. 8, the outer layer **23** being 1/16" thick and the annular ribs **24** being 1/8" thick and spaced 1/4" center to center. Eight vent holes of 1/16" diameter were provided for each chamber **26**. The outer layer **23** was reinforced by thin peripherally stretchable and axially stretch resistant nylon fabric immediately below the outer surface. In its relaxed state the neoprene sleeve had an outer diameter of 4 1/8".

The valve sleeve was wetted with crude oil and then pushed into the casing and produced a tight seal against a differential pressure of 3000 p.s.i. The force required for insertion of the valve sleeve into, and movement of the valve sleeve within, the casing was less than in Test 1. This appears to be due to the near cylindrical shape of the elastomer body which promotes maintenance of a film of lubricant over its surface.

Test 4.—For this test an elastomer sleeve of the shape shown in FIG. 9 was applied to the sleeve valve core. The elastomer sleeve consisted of open-pore polyurethane sponge material of a density of 11 lb. per cubic foot and an extremely fine pore structure. In its relaxed condition the sleeve had an outer diameter of 4 1/2" which after aging in 4" tubing at a temperature of 212° was reduced to 4 5/16". The outer skin of the elastomer was tough and denser than the interior, but porous.

The valve sleeve was inserted into the casing and showed traces of leakage at a differential pressure of 1900 p.s.i.

Test 5.—An elastomer sleeve of the type shown in FIG. 10 was applied to the sleeve valve core. The elastomer sleeve was composed of polyurethane open-pore sponge material of a density of 11 lb. per cubic foot and extremely fine pore size. The material had 1/4" perforations, as shown at **32** in FIG. 10, the perforations being spaced one inch, center to center. The outer diameter of the sponge body was 4 1/4". The sponge body was impregnated with AM–9 gel forming aqueous solution containing 10 percent of NaCl and then heated to 160° F. for 5 minutes to insure complete gelling of the solution. The resulting elastomer was then dried to dehydrate the gel within the pores.

The valve sleeve was inserted into the casing in dehydrated condition and the casing was then filled with water. After 6 hours the valve sleeve was subjected to a differential pressure test and was found to resist 4000 p.s.i. pressure without leaking.

Insertion of the dehydrated valve sleeve into the casing required the least force of all of the tests.

Apparently the superior sealing ability of the elastomer is due to the swelling of the gel component within the pores.

Test 6.—A valve sleeve was constructed according to FIGS. 6 and 7 with an elastomer body of "Nordel" rubber (ethylene propylene hydrocarbon rubber cured with benzoyl peroxide) composed of rings having a diameter of 4 1/6", a width of 1" of the shape shown in FIG. 5. The rubber contained a thin hydrocarbon oil (commercially available as "Flexon 765") in an amount equal to 50 percent of the total elastomer volume. The sleeve was immersed in benzene for 48 hours for the purpose of extracting the plasticizer and then air dried for 48 hours to extract the benzene, at which time the rubber rings had shrunk to an outer diameter of 3 7/8" as shown in FIG. 6. The sleeve was then inserted into the casing filled with crude oil which caused the elastomer body to swell. After 24 hours of swelling the valve sleeve withstood a differential pressure of 4000 p.s.i.

Test 7.—A packer comprising an elastomer layer of 3" length and 3 7/8" outer diameter composed of "Nordel" rubber was placed in a 4" casing and then wetted by hydrocarbon plasticizer oil having a boiling point of 380° C. The elastomer swelled into contact with the casing and produced a seal capable of withstanding 280 p.s.i. differential pressure. The amount of oil used was about 20 percent greater than the amount absorbed by the elastomer during swelling.

After exposure to air for 90 days the seal withstood the same test pressure without leakage.

The test indicates that by swelling the elastomer seal with a swelling liquid of high boiling point, such as plasticizers compatible with the elastomer material, the seal may even be exposed to air after swelling or exposed to a gaseous atmosphere in which swelling liquids of low boiling points, such as gasoline or water, would evaporate too fast to be practical.

This property makes swelled elastomer seals as represented by this test highly useful not only for underground installations but also for above ground use, for example as a seal in water drain ducts.

In all instances the valve sleeves were removed from the casing by forceful extraction against the sealing force of the elastomer to demonstrate the axial displacement of the valve sleeves. The outer diameters after withdrawal were as follows: Test 1—4 3/32"; Test 2—4 1/8"; Test 3—4 3/32"; Test 4—4 3/16"; Test 5—4 3/16"; Test 6—4 3/32".

The elastomers employed in the practice of this invention are preferably of the highly flexible type such as rubber, polyesters, polyurethanes with elongations in excess of 200 percent and a low tendency to set after compression, i.e., materials having high elastic recovery after release from compression over long periods of time, such as 24 months, and temperatures of the order of 160° F.

The elastomers should be chemically resistant to crude oil and salt water at temperatures of the order of 160° F. in the sense that their physical strength should remain substantial even though the material may swell appreciably. Indeed swellability is a desirable characteristic in most instances.

The following were found to be satisfactory: polychloroprene, a substance commercially known as "neoprene" rubber. It exhibts low crude oil swellability. Butadiene acrylonitrile copolymer is commercially known as "Buna N" rubber. It has low crude oil swellability and exhibits low compression set. Polyurethane rubber known commercially as "Adiprene" and "Cyanaprene." Fluoroelastomer rubber commercially known as "Viton" and "Hydelon." Ethylene propylene hydrocarbon rubber is commercially known as "Nordel" rubber. It represents an example of a highly swellable substance. The degree of swelling may be amplified. Oil swellable rubbers are preferably cured in a highly plasticized form. Extraction of the plasticizer by leaching in a volatile solvent, such as benzene, followed by evaporation of the solvent leads to appreciable shrinkage. If the shrunk condition is taken as the starting condition a great increase in volume by subsequent swelling can be produced.

The volume of the plasticizer may range between 25 and 75 percent of the total volume.

The commercially available elastomers of this type contain as plasticizers hydrocarbon oils of high boiling point. Such oils are commercially available under a wide range of trade designations, such as "Flexon 765" or "Flexon 865," "Conoco H–35."

A particularly advantageous form of rubber is cured with a volatile plasticizer such as benzene under conditions preventing loss of the plasticizer during the curing process. In that case subsequent extraction of the plasticizer involves no more than simple evaporation.

Open-pore sponge type elastomers may be of the rubber or the polyurethane type.

Impregnating solutions for producing water swellable gels are made from materials known in the well drilling art as grouting materials. One such grouting material, known by its trade designation AM–9, is composed of 95 parts of acrilamide, 5 parts of methylene bisacrilamide, 900 parts of water and a small amount of a catalyst, such as ammonium persulfate. After mixing with the water the resulting liquid sets to form a stiff gel.

Gels made with pure water in the gel forming solution shrink upon contact with saline underground water such as occur in oil wells. To eliminate such shrinkage I prefer to make gel bodies for underground use from a gel forming aqueous solution containing an inert salt or solute of a concentration at least of the order of that of the saline water to be encountered underground.

Additional swelling results if the solution concentration is made higher than that of the underground saline water. In that case the gel bodies actually swell beyond their normal gel setting volumes upon contact with the underground water of lower concentration.

Solution concentrations of .1 N up to saturation of the inert solute or salt, such as NaCl, is generally satisfactory.

In view of the commercial availability of a wide variety of oil swellable and nonswellable elastomers in solid or porous form, other materials than herein specifically mentioned may be employed. A practical test is conducted by cutting a test strip of about 10 x 20 x 100 mm. which is then subjected to test to determine its tensile strength before and after contact with hydrocarbons, its swellability and the degree to which it may be preshrunk by plasticizer extraction. Plasticized elastomers are commercially available and can be made with different plasticizer contents, such as 25, 50, and 75 percent of total volume.

In conducting tests materials were used which their manufacturer, who was not aware of the intended use, described as "not suitable" or "not recommended" for use in contact with hydrocarbons because of the high degree of swelling experienced in such use. These materials proved very well suited for the practice of the invention, as swellability is a feature, not a disadvantage.

Example 1.—In a well fitted with a cemented casing three potentially productive zones were perforated. The top zone had a vertical spread of the perforations of 14 feet, the intermediate zone 19 feet, and the lowest zone 46 feet. The casing was reamed to remove perforation burrs and otherwise provide a smooth surface.

The zones were then individually tested and treated with the aid of straddle test tools with hydraulically operated packers at each end. It was determined that the upper zone produced salt water only, that the intermediate zone produced oil from the upper 6 feet and water from the lower 13 feet. The lowest zone was found to produce oil and gas from its upper perforations and water from the bottom 17 feet of perforations.

Valve sleeves were then installed to seal the upper zone permanently and to control the flow from the lower two zones. For this purpose the casing was first filled with crude oil by circulation and swabbing through tubing extending to the bottom of the well.

After withdrawal of the tubing a valve sleeve 30 feet in length with "Nordel" rubber sleeves at each end and extending for a length of 4 feet each was gripped by an adjustable internal friction gripper, adjusted to sustain 2½ times the weight of the sleeve. The friction gripper was attached to the end of a wire line, lowered into the casing with the gripped sleeve and maintained at the proper level to shut off the lower 17 feet of the bottom zone. After six hours the swellable elastomer sleeve had swelled sufficiently to seat the sleeve in the casing against the pull of the gripper which slipped out of the sleeve when a pull in excess of 2½ times the sleeve weight was exerted.

The upper 11 foot portion of the bottom zone was closed next by a 24 foot valve sleeve with a 4 foot elastomer covering at each end.

The entire intermediate zone was sealed by a 31 foot valve sleeve with 4 foot elastomer portions at each end, and finally the entire top zone was sealed by a valve sleeve of a total length of 25 feet having 4 foot elastomer portions at each end.

A production string with pump was then installed extending to a point below the bottom zone.

Production was obtained from the uncovered 18 foot portion of the bottom zone. When, after a period of production, the gas/oil ratio and the water/oil ratio increased to an undesired degree, the lower 30 foot valve sleeve was raised and the upper 24 foot valve sleeve was lowered by means of a string of weighted tubing with a gripper or anchor at its lower end.

The gripper grasped the respective sleeve in the manner of an internal chuck, and the sleeve was then moved by application of sufficient force to make it slide.

Eventually the two sleevs within the bottom zone were moved to abut, thereby sealing the bottom zone, and the 31 foot sleeve valve within the intermediate zone was depressed to produce from the upper 6 foot portion thereof.

It is of course also feasable to install several valve sleeves at their desired levels simultaneously by means of a wire line with several gripping tools arranged in series, and sleeves engaged by the gripping tools, properly spaced from one another. When all sleeves are lowered into the casing which is filled with crude oil, they expand simultaneously at their respective positions, whereafter the wire line and the gripping tools are withdrawn.

Example 2.—Three valve sleeves with oil swellable elastomer seals were assembled with the required spacing from one another on a tubing string fitted with mechanically expansible line packers or anchors. The line packers or anchors were expanded by counterclockwise rotation until they gripped the respective valve sleeves securely.

The tubing string was then lowered into the water filled casing of the well. After placement of the sleeves at the desired location crude oil was circulated down the casing and up through the tubing string until all water was displaced from the casing. After 24 hours of immersion of the sleeves in crude oil the valve sleeves were set sufficiently firmly for removal of the string and of the packers or anchors thereon by clockwise rotation of the string, thereby contracting the packers and anchors to free them from the cylindrical center passage of the valve sleeves and permit withdrawal of the string.

The tubing string was then replaced by a production string.

Subsequent axial adjustment was accomplished by reinsertion and tightening of a packer or anchor. For this purpose the tubing was loaded with drill collars as closely to the valve sleeve to be depressed as possible. It was also found possible to move the valve sleeves in relatively small increments up or down by bumping involving impacts on the gripped valve sleeve.

It is possible also to adjust valve sleeves by bumping by means of a wire line or cable tool. Regular cable drilling equipment is well suitable for this purpose.

In all instances the static force for moving a valve sleeve with two four foot elastomer seals ranged between 1 to 4 tons.

Example 3.—Valve sleeves with elastomer seals according to FIG. 2 and composed of neoprene rubber of low swellability compressed by insertion into the casing from an original relaxed diameter of 4⁵⁄₃₂" to a compressed diameter of 4" were moved a total distance of 4200 feet in a reamed casing containing crude oil and were subsequently tested for sealing ability. The sleeves before the 4200 foot travel sealed securely against a differential pressure of 3200 p.s.i. After withdrawal they were found to be effective against a differential pressure of 2800 p.s.i.

Example 4.—A well of 7¾" diameter was drilled and it was determined that a formation of 7 foot thickness was oil bearing.

The well bore was checked by caliper logging and was found to be a smooth-walled bore of 7¾" diameter over a distance of 22 feet above the oil bearing formation and 19 feet below the formation.

In lieu of installation of a casing, a 2⅞" tubing string was installed carrying near its lower end a straddle tool capable of establishing a hydraulically tight connection between the tubing interior and the oil bearing zone as follows:

The straddle tool is diagrammatically shown in FIG. 16 and consisted of a steel sleeve **411** of 6" outer diameter and 21 feet length with elastomer seals of "Nordel" rubber at each end extending over a distance of 5 feet from the end of the sleeve. Each seal consisted of a series of individual rings having an outer diameter of 7¼", a width of 4" and a thickness of ½". V-shaped valleys are formed between successive rings.

The rings are built up from strips of rubber $\frac{1}{16}$" in thickness and reinforced with nylon fabric resisting axial elongation but permitting radial expansion. About 8 turns of the strip material forms the ½" thickness of the ring which after winding are cured to assume their final unexpanded shape.

The sleeve **411** was connected to the tubing **39** by spiders **41** and **42** permitting passage of liquid through spider apertures **43** from the space above the straddle tool to the space below and vice versa.

Passages **44** temporarily sealed by aluminum plugs **45** were provided to establish communication between the interior of the tubing string **39** and the annular space **46** defined by the elastomer seals **16**, the well bore **31** and the sleeve **11**.

The tubing string was lowered into the well to a position in which the sleeve straddled the formation, the bottom end of the string extending 50 feet below the straddle tool. The well bore was then filled with crude oil containing about 40 percent gasoline by volume by circulating the oil down the tubing and up the tubing by swabbing.

After 48 hours the elastomer seals had expanded to form a fluid and pressure tight seal.

In order to prevent or reduce leakage from the spaces above and below the straddle seal through fractures or porous portions of the formation, the oil in the annular space above and below the sleeve was replaced by a slurry of Bentonite and gel particles made by grinding AM–9 gel. The slurry effects a seal of porous portions which tend to form a passage for leakage liquid.

The tubing was then sealed below the straddle tool with a packer and the plugs **45** were dissolved by 1 N NaOH in water solution, whereafter the installation was ready for production.

Example 5.—A valve sleeve was constructed according to FIG. 6. The sleeve was 18 feet in length and comprised water swellable elastomer seals of 4 feet length at each end. The sleeve was installed in a well casing of 4" inner diameter to straddle perforations in the casing and in the oil bearing zone about it, the perforations being within a vertical spread of 6 feet. The elastomer layers were bonded to the valve tubing and consisted of cellulose sponge cloth of ½" thickness impregnated with a gel formed of AM–9 gel compound and 8 percent aqueous NaCl solution, subsequently dried and shrunk to an outer diameter of 3⅝".

The valve sleeve was then lowered into the water-filled casing by wire line and gripper. After 6 hours the elastomers had swelled to seat tightly in the casing and seal the perforations. The packer was tested and did not leak at 3000 p.s.i. of external overpressure. The well was then tested below the sealed zone and after 18 days the packer was pulled upwards in the casing for a distance of 20 feet by wire line and gripper to uncover the perforations. The well was then produced from this zone.

What is claimed is:

1. In the combination of

(a) a well casing,

(b) a cement layer between said casing and its surrounding formation, there being

(c) perforations extending through said casing and said cement layer into the formation;

and a valve sleeve within said casing, the sleeve comprising

(I) a central tubular rigid metal core providing a central passageway for fluid axially through the sleeve,

(II) and an outer covering of elastomer material secured to said tubular core, said covering comprising, in alternating sequence, substantially annular elastomer portions and substantially annular void portions,

the improvement according to which said outer covering in its relaxed condition has an external diameter larger than the internal diameter of the casing, the outer covering being inserted into the casing

(a) in radially compressed condition, thereby displacing a portion of the elastomer annuli into said void portions, and

(b) presoaked in a hydrocarbon liquid before insertion into the casing, thereby providing a lubricating film between said covering and said casing.

2. The combination as claimed in claim **1** in which the covering of elastomer material comprises an inner sleeve portion from which annular rib portions extend outwardly forming annular void spaces of substantially V-shaped cross section between successive ribs.

3. The combination as claimed in claim **1** in which the covering of elastomer material comprises a common outer sleeve portion for bearing against said casing, and annular rib portions integral with said sleeve portion, said rib portion extending inwardly towards said metal core.

References Cited

UNITED STATES PATENTS

500,558	10/1895	Fraser et al.	166—23
672,255	4/1901	Boberg	277—123
2,094,691	10/1937	Williams	277—1
2,452,466	10/1948	Jaswell	166—179
2,849,070	8/1958	Maly	277—11
2,945,541	7/1960	Maly et al.	166—187
3,067,819	12/1962	Gore	166—179
3,134,442	4/1964	Jennings	166—207

JAMES A. LEPPINK, *Primary Examiner.*

UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 3,385,367 May 28, 1968

Paul Kollsman

It is certified that error appears in the above identified patent and that said Letters Patent are hereby corrected as shown below:

Column 10, line 15, "sleevs" should read -- sleeves --. Column 12, line 51, "500,558" should read -- 50,558 --.

Signed and sealed this 16th day of December 1969.

(SEAL)
Attest:

Edward M. Fletcher, Jr.
Attesting Officer

WILLIAM E. SCHUYLER, JR
Commissioner of Patents