# EXPERT KNOWLEDGE OF ELASTOMER COMPONENTS

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# The Most Versatile Sealing Element of all Time: The O-Ring

## A Review of the History of its Origins and an Outlook on its Potential


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## 1. Definition, Applications and Advantages of the O-Ring

The "O" in the term O-ring refers to the round cross-section of this ring. Meanwhile, this term has established itself in technology. Before the term "O-Ring" was used in English, the terms "Round Ring", "Toroid Ring", "Donut Seal"[1] and "Toroidal Sealing Ring"[2] were also common.
Today, O-rings are used in billions of pieces both in static and dynamic applications (e.g. hydraulic or as a seal on a rotating shaft) as a seal. Its many advantages have made it an "all-rounder" in sealing technology. O-ring seals show good sealing properties even at low surface

[1] ALLEN, Robert E.: "O" Rings Make History, Otterbein Publishing Co., Dayton, Ohio, 1969, S. 8
[2] Vgl. British Standard 1806 / 1951: Dimensions of Toroidal Sealing Rings, British Standards Institution, London, 1951

pressures - assuming sufficient deformation - which do not deteriorate even over very long periods of use despite considerable stress relaxation or aging of the material. Depending on the cord thickness, gaps of up to approx. 0.5 mm and more can be bridged with O-rings. Due to the enormous variety of ever more efficient elastomer materials from which O-rings are made, O-rings can be used from -70°C to approx. +300°C, depending on the elastomer type. O-rings can be used to seal both ultra-high vacuum (10-8 Torr) and high pressure applications (400 bar, special cases 2000 bar). In addition to its good installation properties, its worldwide availability and low price are further advantages that have made the O-ring the most common and perhaps also - not only among buyers - most popular type of sealing of all time. The simple design of an O-ring has also become a well-known fact among many designers. And finally, the fact that many users are not even aware of how often they rely on the perfect function of O-rings every day is actually the very best argument for the reliability of O-rings.



## 2. Who Invented the O-Ring?

Due to the extremely simple geometry, which could already be produced in the middle of the 19th century in the quality usual at that time, it is difficult to name a certain inventor of the O-ring. However, there are people who were important for the introduction of the O-ring into new applications.
This shows an analogy to the history of the discovery of rubber cross-linking and the numerous researchers and inventors associated with it: [3]

As early as 1832, the German chemist Friedrich W. Lüdersdorff (1801-1886) described the vulcanization process. He solved the problem of sticky rubber coatings, e.g. on textiles, by sprinkling them with powdery sulphur.[4]
A similar discovery was made by the American Nathaniel Hayward in 1834.
However, it was not until 1839 that Charles Goodyear actually discovered the vulcanization of natural rubber. Parallel to Goodyear, Thomas Hancock also registered a patent for vulcanization in 1845.

But now back to the O-rings: Probably the earliest patent for a dynamic O-ring application (see **Fig. 1**) originates from Great Britain and was granted in 1848. The inventor was a certain Alonzo Buonaparte Woodcock from Manchester. He was a man who was very familiar with rubber and its properties. Alonzo Woodcock worked with Thomas Hancock for many years and was plant manager at Macintosh in Manchester.[5]
In his patent No. 12,253 of February 22nd, 1848 Woodcock describes the possible use of O-rings in steam engines, e.g. in their stuffing boxes, pumps, valves or taps. He already mentions the necessary compression of the O-ring cross-section into an elliptical shape.[6] In order to

[3] Vgl. RÖKER, Klaus-D.: Vulkanisation – chemische Reaktion oder Adsorptionsvorgang? Eine Kontroverse zu Beginn des 20. Jahrhunderts in: Mitteilungen, Gesellschaft Deutscher Chemiker / Fachgruppe Geschichte der Chemie, Frankfurt/Main, Bd 20, 2009, S. 68
[4] SCHNETGER, J.: Lexikon der Kautschuktechnik, Hüthig-Verlag, Heidelberg, ²1991, S. 370
[5] LOADMAN, John und JAMES, Francis: The Hancocks of Marlborough: Rubber, Art, and the Industrial Revo-lution: A Family of Inventive Genius, Oxford University Press, 2010, S. 117
[6] GB-Patent No. 12,253 vom 22. Februar 1848, Erfinder: Alonzo B. Woodcock: Steam Engines, and Apparatus for

reduce seal wear and avoid lubricants such as oil, he suggests an O-ring that rolls during piston movement.

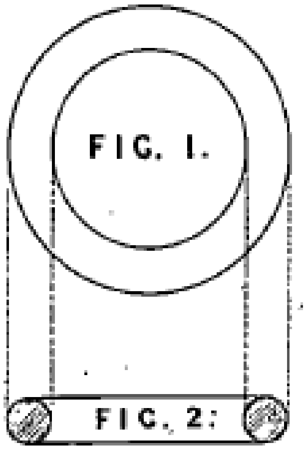


**Fig. 1:** Probably one of the earliest O-ring representations[7], from a patent from 1848 by Alonzo Woodcock:
*„…elastic rings of a cylindric or other suitable form, and of any suitable elastic material, as india rubber (caoutchouc)…, but I prefer rings of india rubber …now well known by the name of vulcanized rubber…"*[8]

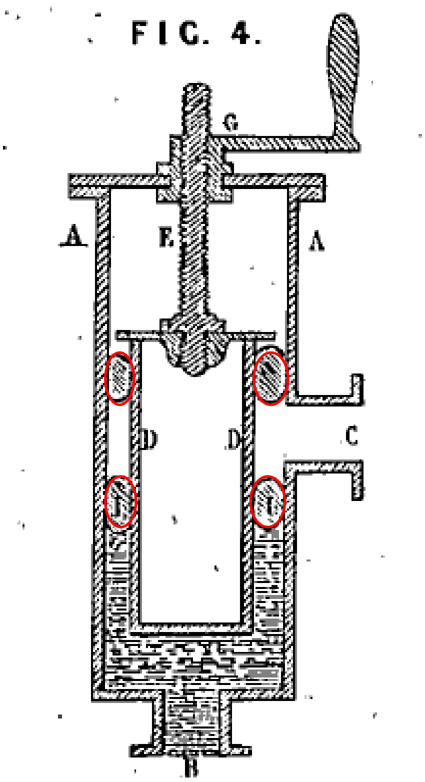


**Fig. 2:** Section of GB patent 12,253 of February 22nd, 1848 by Alonzo Woodcock: Device for conducting water or other liquids. By turning the lever G the piston D moves upwards, the O-rings marked with red ellipses roll down and water can flow from B to C.[9]

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Raising and Forcing Water, &c., S.3
[7] Ebd., S.7
[8] Ebd., S.2f.
[9] Ebd., Beschreibung: S. 4 und Fig. 4 S.7

Using O-rings as rolling sealing elements seems to have been of particular interest to the inventors of that time. Since there was probably no defined rolling of the elastic seals on relatively smooth piston and cylinder walls, a patent with an improvement was proposed in the USA in 1856[10] (**Fig. 3**).

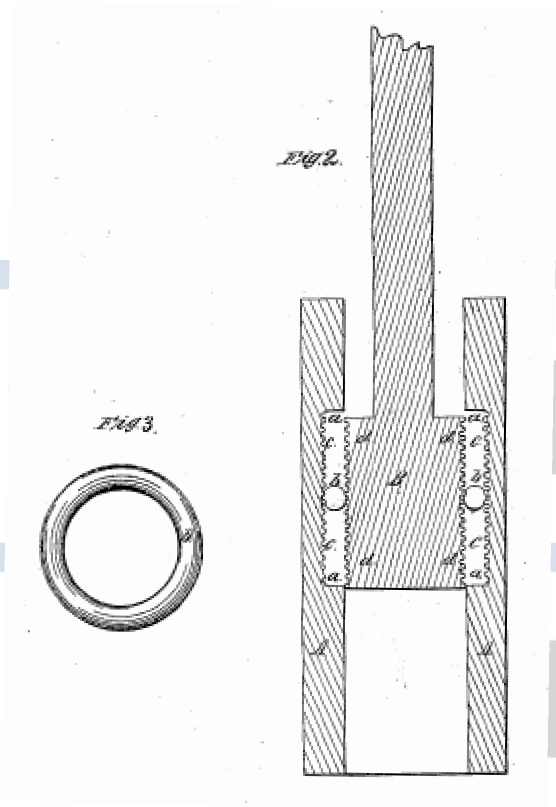


**Fig. 3:** Excerpt from US patent 16,202 dated December 9th, 1856: Cylinder and Piston of Hydraulic and Steam Engines: The inventor John Underwood describes in it a cylindrical ring (**Fig. 3**) made of "India rubber" or another elastic substance.

John Underwood's invention, patented in December 1856, describes the use of a cylindrical rubber ring that can also be made of another elastic material. The grooves on the cylinder were supposed to act like the teeth of a tooth rack and the O-ring was supposed to act as a pinion. This patent also emphasizes the importance of sufficient compression of the O-ring to perform its sealing function.[11]

Another US patent with a non-static O-ring seal date from 1868 (**Fig. 4**). Here, O-rings perform sealing functions in an improved version of a valve tap. This is a design in which the sealing ring can roll in a defined manner on a piston piece.

[10] It cannot be ruled out that there are still earlier patents describing the use of O-rings. These small sealing elements are often concealed in larger patents, so that their detection requires much detective skill and time. The authors of this text are grateful for information on earlier O-ring applications.

[11] "…the diameter of the piston is such that it will fill the ring when in the chamber of the cylinder and *give the ring a proper pressure.*" in: US-Patent No. 16,202, dated December 9, 1856: Inventor: John Underwood: Cylinder and Piston of Hydraulic and Steam Engines, S.2

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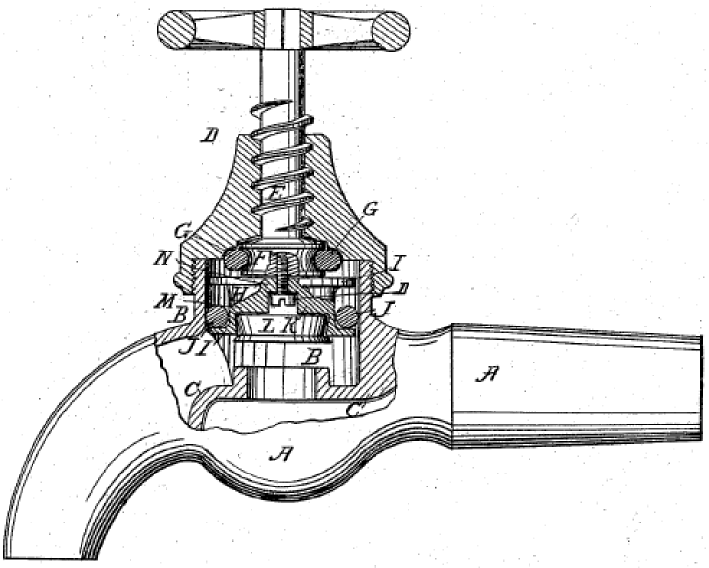

**Fig. 4:** US Patent No. 80,066 of 21 July 1868 by John B. Gibson on the improvement of a valve tap: The letters G and J identify O-rings ("a band or ring, G, of vulcanized rubber" and "a ring of circular section, of India rubber, J").[12]



Since the rubber O-ring is a component of these patents, but is not mentioned as a separate, previously patented sealing element, it can be assumed that O-rings were already in use as sealing elements before 1848. The patents presented use O-rings in dynamic applications that were already quite bold at the time. It can therefore be assumed that O-rings were certainly used in simple static seals before 1848 and were probably already a standard sealing element in technology.[13]

An overview of the early patents with O-rings, mainly in dynamic applications, can be found in a 1964 patent lawsuit filed by N. Christensen's heirs against the United States of America[14]. Since patent lawsuits often involve large sums of money, it can be assumed that the search for predecessor patents has been carried out thoroughly.

The early or allegedly first O-ring patents frequently cited on the Internet, such as the sealing ring in Th. A. Edison's light bulb 1882 (US Patent No. 263,878) or the Swedish Patent No. 7679 by J.O. Lundberg from 1896, are not first mentions of O-ring seals, but there were already numerous similar static and dynamic O-ring applications before these publications.

The breakthrough of the O-ring took place through the inventions of a certain Niels Christensen[15] who was born on August 16th, 1865 on a farm in Toerring, Denmark. After an

[12] US-Patent No. 80,066, vom 21. Juli 1868: Erfinder: John B. Gibson: Improvement in Valve-Cocks, S.2

[13] “Resilient round sealing rings were used at least as early as the mid 1800's with mixed success” in: http://logwell.com/tech/O-ring/index.html

[14] 339 F.2d 665 Jo. C. CALHOUN, Jr., and Esther C. Young, Executors of the Estate of Niels A. Christensen (Deceased) v. The UNITED STATES No. 432-55. (Online verfügbar: https://openjurist.org/339/f2d/665/calhoun-v-united-states#fn-s oder https://law.resource.org/pub/us/case/reporter/F2/339/339.F2d.665.432-55.html )

[15] The following biographical information is according to: WISE, George: Ring Master in: American heritage’s invention & technology, Bd. 7, Spring/Summer 1991, S.58-63

apprenticeship as a machinist, he studied at the Technical Institute in Copenhagen. Among other things he worked at the largest lighthouse in Denmark, later in Great Britain (Newcastle upon Tyne), until he emigrated to the USA in 1891. A major tram accident in 1893 in Oak Park, Illinois brought his attention to the improvement of braking systems. Many of his patents deal with pneumatic or hydraulic systems. Around 1895 he founded the Christensen Engineering Company in Milwaukee, which he soon left again, partly because of his uncompromising nature.
From 1933 he worked on what was probably his most significant invention in his laboratory: the search for a simple and reliable seal that would not hinder the movement of hydraulic pistons but would nevertheless reliably seal them. Tests with O-rings had already been carried out before him, but this type of seal proved not to be durable for long. He began to experiment with different O-ring and groove dimensions.

**Fig. 5:** Niels Christensen (1865-1952) in a photograph taken in 1906[16]



Finally, he achieved his best results in grooves with about 1 ½ times the value of the cord strength.

Christensen wrote in his notebook on 20th September 1933:

> "This gasket has been tested over 2,790,000 strokes over ½ inch (= 12.7mm) at 60 psi (= approx. 41bar) and over 2,790,000 reverse strokes at ambient pressure. This gasket never showed any leakage and is still tight and no liquid passed through it during the entire test. The ring retained its original shape and worked perfectly."[17]

Christensen was a researcher who relied more on his positive results and practical experiments than on the theory behind them. Through his tireless trial and error, he had now found a groove/ring combination that surpassed all previous sealing systems.

[16] Quelle der Fotografie: National Engineer publication - August 1906 edition of the National Engineer, Public Domain, https://commons.wikimedia.org/w/index.php?curid=42477057
[17] ALLEN, Robert E.: “O” Rings Make History, Otterbein Publishing Co., Dayton, Ohio, 1969, S. 3

The function of this sealing system was only discovered in 1941 by a transparent cylinder in the laboratories of Vought-Sikorsky: "In this cylinder [the researchers] observed a rolling of the seal by about 20° when pressure was applied, and the piston began to move. They also observed that this gasket in the groove slides away from the pressure in a certain winding pattern and that the pressure distorts the gasket into a "D" shape to increase the width of the gasket surface from about 30% of the cord thickness to 40-60%."[18]
A few years later Lockheed examined the function of the O-ring seal with a color film. This enabled important insights to be gained into the movements of the O-ring, such as rolling, sliding or wiping, but also into the liquid movements caused by the O-ring.
But back to Christensen: On December 29, 1933, he filed a patent for a hydraulic brake (**Fig. 6**), which was granted to him on April 26, 1938. In it, he already used O-rings.

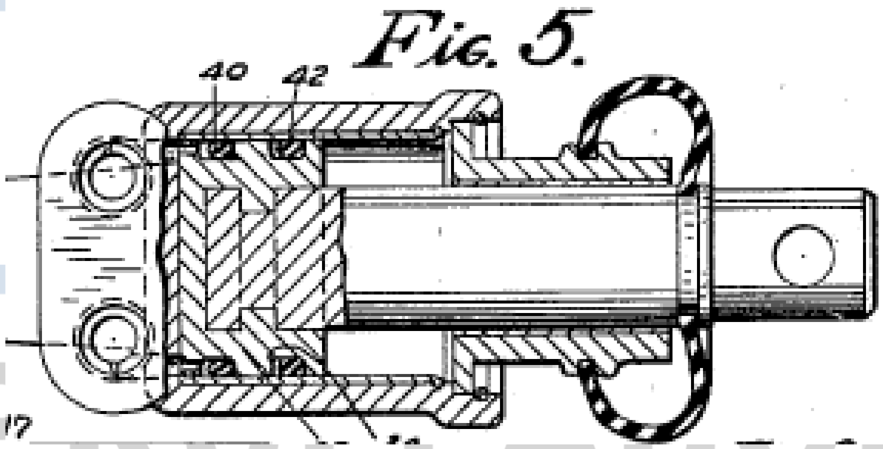


**Fig. 6:** Excerpt from US Patent No. 2,115,383 of April 26th, 1938: Hydraulic Brake by N. Christensen (No. 40 shows an elastic sealing ring with a backup ring (42) in case the former O-ring should fail) [19]

In 1937 he applied for a second patent, which was granted to him on November 21st, 1939 with the number 2,180,795 (**Fig. 7**). In it he describes a functioning O-ring seal, although he did not fully understand the actual functional mechanism. He believed that the service life of the seal would be extended by continuous kneading and milling - similar to a muscle.[20] New and important for later patent suits was, among other things, his patent claim 1, in which he demanded that the ring must not rotate more than 180°.

[18] ALLEN, Robert E.: "O" Rings Make History, Otterbein Publishing Co., Dayton, Ohio, 1969, S. 5
[19] US-Patent No. 2,115,383 vom 26.April 1938, Erfinder: Niels Christensen: Hydraulic Brake, S.1
[20] US-Patent No. 2,180,795 vom 21. November 1939, Erfinder: Niels Christensen: Packing, S.3

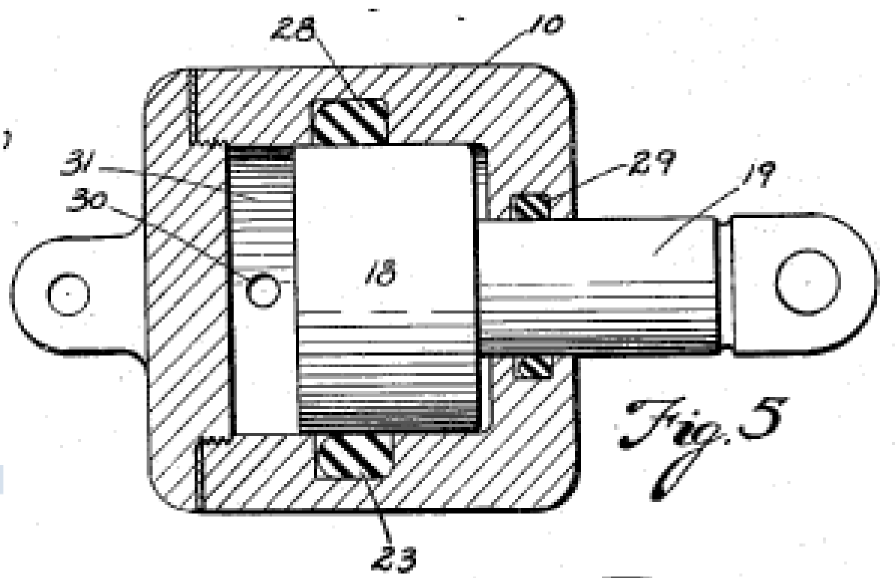


**Fig. 7:** Extract from the most important O-ring US patent No. 2,180,795 dated November 21st, 1939: "Packing" by N. Christensen (In addition to variants of piston seals in this patent, a rod seal is also shown): The O-ring No. 28 seals the piston on the outside and is installed in the cylinder). [21]

In April 1943, he filed a third patent for a pressure seal, which was granted to him on February the 5th 1946 with the number 2,394,364.

Initially it was difficult for Christensen to find licensees for his 1939 patent. Since the automotive industry did not want to replace the existing seals in brake cylinders, Christensen went to the aerospace industry. After positive attempts around 1940, he granted in April 1941 a non-exclusive license to United Aircraft Products Co. with royalties between 15 US$ cent and 2 US $[22], depending on the O-ring size.

To facilitate armament during the war, the US government bought important patents after Pearl Harbor, including Christensen's O-ring patent in October 1942 for $75,000. For a period of 5 years or until the end of the "National Emergency", anyone could use this seal for military aircraft free of charge. A disadvantage for Christensen was that President Truman did not declare the war officially ended in 1945, but only in 1952, so that Christensen only had 4 years of remaining use of his patent.[23]

After a lengthy patent dispute in 1971[24], US$100,000 was paid to his heirs for lost license royalties.

In this trial of Christensen's heirs against the United States, a British patent of Stewart Robertson threatened to tip over to a toilet flush (No. 10,716 of 14.10.1899, see **Fig. 8**), Christensen's patent. In this British construction, O-rings were used as early as 1899 in a rectangular groove that was only slightly wider than the cord thickness of the ring. The lawyer Calhoun could prevent[25] the invalidity of the Christensen patent by referring to the exact

[21] US-Patent No. 2,180,795 vom 21. November 1939, Erfinder: Niels Christensen: Packing, S.1
[22] Zur Information: 1 US $ im Jahr 1940 entspricht 2018 einer Kaufkraft von 15 US$ oder mehr (je nach Berechnungsgrundlage).
[23] At that time, a patent was still valid in the USA for 17 years from the date of issue: The first O-ring patent 2,180,795 was granted in November 1939.
[24] Vgl. https://en.wikipedia.org/wiki/Niels_Christensen (Zugriff auf Webseite am 23.01.2018)
[25] WISE, George: Ring Master in: American heritage's invention & technology, Bd. 7, Spring/Summer 1991, S. 63

formulation of Christensen that the cross section of the O-ring must be pressed in a kind of elliptical form [26].

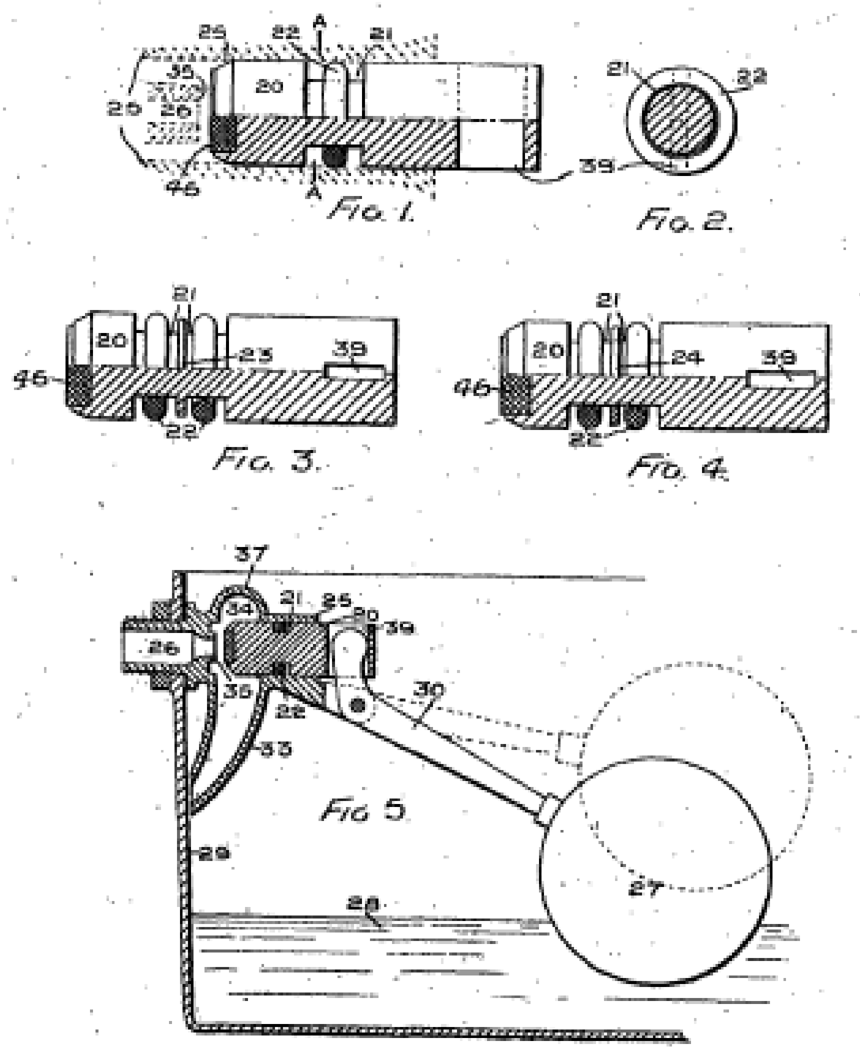

**Fig. 8:** Excerpt from the British patent No. 10,716 of 1899 on improvements of a valve for toilet flushing or similar: Fig. 3 and Fig. 4 represent variations of Fig.1 with only one O-ring. New and noteworthy here is the rectangular groove (21), which is only slightly larger than the rubber ring (21). Here the O-ring is already installed on a moving cylinder.[27]

For a long time, Niels Christensen was a forgotten inventor. This may have been connected to his uncompromising and less diplomatic nature. In 1989, the laboratory director of Midland Steel, to whom Christensen had offered his patent unsuccessfully, remembered that he could be unforgivable if he could prove technical errors to people: "He dismantled them into nothing and then jumped on their bloody remains."[28] On the other hand, however, the state purchase

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[26] "…when the ring is in the groove in operative position, it is compressed into somewhat ellipsoidal cross-section,.." US-Patent No. 2,180,795 vom 21. November 1939, Erfinder: Niels Christensen: Packing, Patentan-spruch 5, S.5
[27] GB Patent No. 10,716 vom 14. Oktober 1899, Erfinder: Stewart Robertson: Improvements in or relating to Ball Valves for Flushing or Supply Cisterns or the like, S.7, sheet 1
[28] WISE, George: Inventors and Corporations in the Maturing Electrical Industry, 1890-1940, Chapter 16 mit Teilen

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of his patent and the late declaration of the official end of the war, 1952, certainly had the largest part in his forgetting. It is therefore easier to understand that the British scientist and researcher on the history of science, Dr Allan A. Mills, did not come across the name Christensen in 1996, despite extensive research in his article "Who invented the O-Ring"[29].
With the help of today's Internet-based search facilities, the name of this prominent inventor has finally been saved from oblivion.

In Germany, O-rings were produced under the designation Schnurringe before 1937, as a glance at the literature shows. In 1935 Paul KLUCKOW wrote in an essay on technical rubber goods about the use of "cord rings for sewing machine spools, separators, honey extractors, pram and toy scooters."[30] However, these are all applications in which O-rings have not taken on a higher sealing function.
As early as 1931, it was known that the production of good O-rings was not an easy production task: "Cord ring molds are only made by special factories because the production requires precision work."[31] At that time, slotted O-rings were already manufactured, as the rubber magazine continues: "Larger cord rings in weak cord thicknesses are cut from injected cord and assembled."
In a US-American analysis of German aircraft hydraulic systems during the second World War in 1946, the use of O-rings was found only in one case and only in a few units (V.D.M. Luftfahrtwerke GmbH, Großauheim). In the other cases, mainly rod seals ("U-cups") with variations (e.g. "half U-cups") were used.[32]
From the 1950s, at the latest from the 1960s, the O-ring was also widely used in industrial applications as a sealing element in Germany.
Another important, but also tragic milestone for the further development of O-rings was the Challenger catastrophe on January 28, 1986, when a relatively low launch temperature and a faulty seal construction caused the space shuttle to explode 73 seconds after launch, costing the lives of 7 astronauts.
The investigations carried out as a result of this accident and countless publications led to an even deeper understanding of the potential, but also the risks, of incorrect use of O-rings and elastomer materials
In the meantime, the O-ring and its design are becoming more and more the subject of scientific investigations, especially with the aid of FEM simulations. In addition, better models for aging and life prediction of O-rings are being developed and researched.[33]

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über Niels Christensens Leben in: WEBER, Robert J. und PERKINS, David N.: Inventive Minds: Creativity in Technology, Oxford University Press, 1992, S. 305
[29] MILLS, Allan A.: Who Invented the O-Ring in: Sealing Technology, No. 31, 1996, S.10-11
[30] Translated from KLUCKOW, Paul: Technische Gummiwaren in: HAUSER, E.A.: Handbuch der gesamten Kautschuktechnolo-gie, Union Deutsche Verlagsgesellschaft Berlin, 1935, Bd. 1, S.441
[31] Translated from Ohne Autorenangabe: Die Fabrikation technischer Formartikel in: Gummi-Zeitung, Band 46, 1931, S. 116
[32] DAVIES, R.H.: German Aircraft Hydraulic Systems and Their Components in: SAE Journal (Transactions), Vol. 54, No. 8, August, 1946, S. 419
[33] Z.B. KÖMMLING, Anja: Alterung und Lebensdauervorhersage von O-Ring Dichtungen, Dissertation, TU Berlin, 2017

## 3. Function of the O-Ring

The sealing effect of the O-ring results from the deformation of its round cross-section by approx. 10-35%, depending on the application and cord thickness. The greater the compression, the larger the sealing or contact surface. The design of the sealing surfaces of both the O-ring and the mating surface have a significant influence on the sealing effect.
In applications with increased pressures, an O-ring seal is additionally activated by the system pressure. The higher the pressure, the higher the surface pressure generated on the sealing surfaces, and at the same time the O-ring will contact the sealing surface better due to the flexing work (see **Fig. 9**). This is based on the largely incompressible nature of the material. Elastomers behave similarly to a Newtonian liquid, which means they have a load-independent viscosity. In addition, the pressure activation also promotes the (pressure-dependent) flexing work of the O-ring. The higher the pressure, the higher the surface pressure generated on the sealing surfaces, and at the same time the O-ring will adhere better to the sealing surface due to the flexing work. In low-pressure applications, on the other hand, the O-ring "lives" exclusively from the restoring potential of the respective O-ring material.

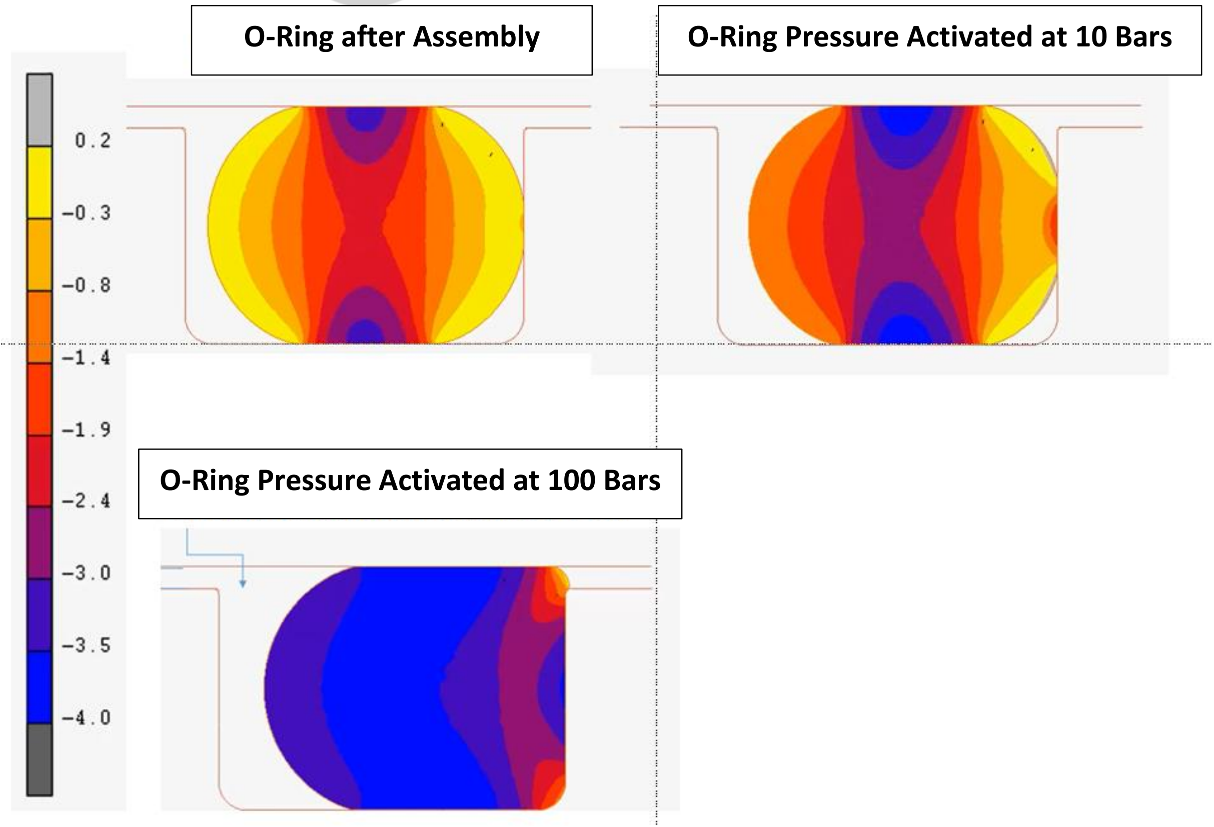


**Fig. 9:** O-rings are able to convert pressures into increased sealing surface pressures due to their largely incompressible nature, high internal strength and pressure-dependent flexing work (FEA illustration: Dr. Manfred Achenbach, www.gutach-ten.de ).

### 3.1 Requirements for a Good Sealing Function

The following three areas are important for a problem-free sealing function:

- Groove Design
- Properties of the O-ring
- Assembly

The groove should be dimensioned in such a way that sufficient pressing is ensured even with unfavorable tolerance positions. This is usually ensured by a worst-case analysis using the design apps of the O-ring suppliers. The designer interested in the background should study DIN ISO 3601-2 (Edition 2010-08: "Fluid Power - O-Rings - Part 2: Installation Spaces for General Applications"). Besides sufficient surface qualities, the machining process or surface structure and the roughness should also be defined. It should also be ensured that no sharp edges can damage the O-ring. Furthermore, excessive gap dimensions must be avoided. A gap that is too large can lead to an inadmissibly strong local reduction of the O-ring deformation if the components to be sealed are eccentrically positioned. In addition, system pressures above approx. 50 bar can destroy the O-ring by gap extrusion if the gap dimensions are too large, depending on the O-ring hardness.

The O-ring itself should comply with the required dimensional tolerances, should have no impermissible surface defects (see DIN ISO 3601-3) and should also show good material properties. The O-ring quality can best be described as a multiplicative combination of "formulation quality x manufacturing quality". "If one factor is close to zero, the whole product is close to zero. Even the best data sheets or formulation qualities are useless if the materials are poorly processed, which means poorly vulcanized. On the other hand, the best quality processes of an O-ring manufacturer are of no use if he processes compounds that do not represent the state of the art, because the compounds used have only been optimized to ensure processability, for example. In order to ensure a good state of the art for O-rings, both must be defined: the formulation (via material properties) and the vulcanization (via compression set requirements for the O-rings)".[34] It is surprising that it took until 2015 to finally standardize the functionally important material properties of O-rings (ISO 3601-5 Edition: 2015-04). This makes it easy to understand that a consistent and well-planned incoming goods inspection of seals pays off and can improve the application safety of O-rings.

Finally, assembly still plays an important, but often underestimated, role, especially in the case of O-rings. This means that impurities on the sealing surfaces must be avoided and any confusion with other O-ring materials or dimensions must be ruled out. In addition, the O-ring must not be pulled over sharp edges that could injure it. Ultimately, this requires a high degree of care and, generally speaking, the use of lubricants such as assembly greases or oils or coatings.

[34] Translated from RICHTER, Bernhard: O-Ring wird zum Normteil in: BERGER, Karl-Friedrich und KIEFER, Sandra: Dichtungs-technik Jahrbuch 2016, Mannheim, 2015, S.194-203

### 3.2 The O-ring as static and dynamic seal

In static seals, the O-ring is almost unbeatable due to its simple geometry, availability and price. It "is particularly well suited as a sealing element for static surfaces because it activates the sealing process as a result of the preload and increases the contact pressure on the sealing surfaces when the applied load increases".[35]

While statically installed O-rings tolerate dynamic pressure and gap changes to a surprisingly high degree, the O-ring quickly reaches its limits as a seal between two moving surfaces. However, for most dynamic applications there are better technical solutions in terms of friction, gap bridging capacity and service life.

## 4. The Diversity of Elastomer Materials - The True Reason for Successfully Using O-Rings



O-rings can be made from practically any elastomer compound that can be processed by compression or injection molding. However, certain types of elastomers have become more widely accepted due to their chemical and thermal resistance and/or low price.
ISO 3601-5 with its **Table 1** on frequently used elastomers and hardnesses for O-rings in industrial applications provides a good insight:

| Elastomer Type | Cross-Linking System | Hardness [IRHD°, CM] | Resistant Against |
|---|---|---|---|
| NBR | Sulphur | 70, 90 | mineral oils, cold water |
| NBR | Peroxide | 75, 90 | mineral oils, cold water |
| HNBR | | 75, 90 | engine oils, cooling water |
| FKM | | 70, 75, 80, 90 | oils, fuel and many chemicals, including aggressive ones |
| VMQ | | 70 | hot air, moderate oil resistance |
| EPDM | Sulphur | 70, 80 | brake fluid, cooling water |
| EPDM | Peroxide | 70, 80 | brake fluid, cooling water |
| ACM | | 70 | engine oils, transmission oils |

**Table 1:** Frequently used elastomers and hardness grades in industrial applications according to ISO 3601-5[36]

[35] PARKER-PRÄDIFA: O-Ring Handbuch, Ausgabe 07/2015, S.9 (Online verfügbar: https://www.parker.com/literature/Praedifa/Catalogs/Catalog_O-Ring-Handbook_PTD5705-DE.pdf )
[36] Nach ISO 3601-5: 2015-04: Fluid power systems - O-rings – Part 5: Specification of elastomeric materials for industrial applications, S.2, Table 1

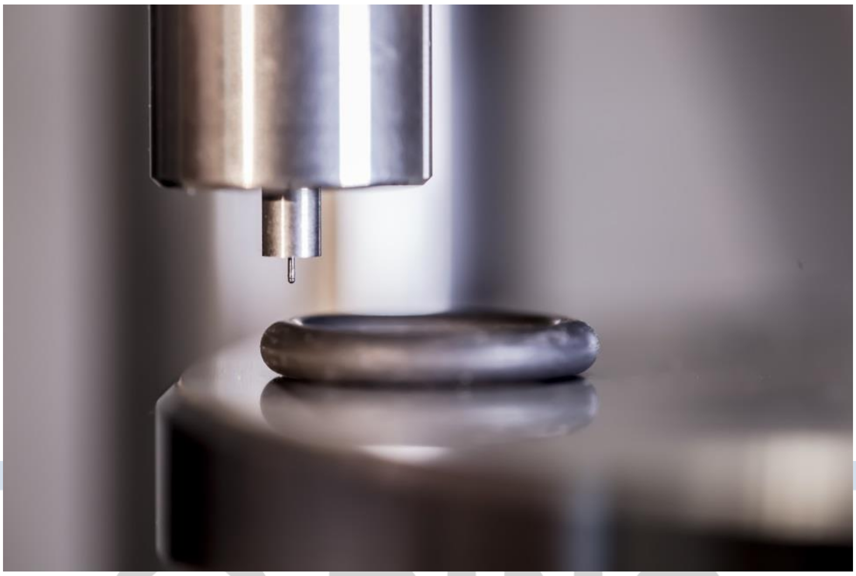

**Fig. 10:** Hardness test on an O-ring (method IRHD, CM) (Photo: O-Ring Prüflabor Richter GmbH)

## 5. O-Ring Coatings

Up to 10% of all seal failures are due to faulty assembly, most of them due to missing or insufficient lubrication. Coatings of O-rings can also have other objectives in addition to facilitating assembly, such as avoiding stick-slip effects, reducing noise, increasing abrasion resistance or color coding to avoid mix-ups.
The benefits of assembly coatings can refer to the avoidance of bonding and the trouble-free automatic feeding of O-rings as well as the reduction of mating forces. Once the O-rings have been mounted without damage, the further advantage, depending on the coating, may be to reduce the breakaway forces or dynamic friction forces at least for a limited number of cycles. Several different types of surface treatments are available:

- Wet coatings (e.g. pastes, greases, hydrocracked mineral oils (Molykote®), synthetic oils, liquids (PAO))
- Dry coatings / bonded coatings (in the form of coatings or dispersions)
- Powder coatings (e.g. graphite powder)

The introduction of plasma processes for the pretreatment of O-rings and the development of new bonded coatings has continuously expanded the range of high-quality coatings and therefore the areas of application for O-rings. Dry coating processes, for example, prevent the dispersion of lubricants such as silicone oil and contribute significantly to improving the quality of various product groups.

## 6. Important O-Ring Characteristics (Standardization, O-Ring Prefabricated Part Testing)

For a long time, O-rings were only specified by large companies in their house standards, which made it difficult to compare different O-rings. It was also unclear whether these in-house specifications always required the full potential of the compound and possible processing quality or whether they adapted more to the capabilities of a particular supplier.

A few decades ago, there were already attempts to establish standards for the formulation quality of elastomers above those of individual manufacturers. A well-known example of this is the ASTM D 2000, which, however, was found to be too complicated and not practical in Europe and could therefore not be established.[37] Moreover, these specifications are very manufacturer-friendly, meaning that the limit values are partly generously set for the suppliers and refer exclusively to ideally vulcanized test plates without any specifications for the degree of vulcanization of finished parts. Finally, with ISO 3601-5, which was published in April 2015, the user now has a powerful tool at his disposal. For the first time, both O-ring materials and properties of the finished O-ring product are specified. When ordering according to this standard, the user now has the security of receiving an O-ring according to a good state of the art, both in compound and processing quality.

Parts 1-4 of ISO 3601 are also helpful for practitioners:

- Fluid Power - O-Rings - Part 1: Inner Diameter, Cord Diameter, Tolerances and Designation Key (Edition 2012-07)
- Fluid Power - O-Rings - Part 2: Installation Spaces for General Applications (2016-07 edition)
- Fluid Power Systems - O-Rings - Part 3: Quality Acceptance Conditions (Edition 2005-11)
- Fluid Power - O-Rings - Part 4: Support Rings (Edition 2008-06)

O-rings are not only very versatile sealing elements in application, they are also suitable for carrying out most test methods in the field of elastomer testing without a long pre-treatment of the specimens. Many users are aware that there is sometimes a large discrepancy between the material properties of test plates and those of finished parts. For most O-ring dimensions, hardness, tensile testing[38] or compression or tensile sets[39] can be performed without any problems. However, the results cannot be compared one-to-one with values measured on test plates.

There is a separate ASTM standard for testing O-rings. ASTM D 1414 (Standard Test Methods for Rubber O-Rings) standards tensile tests, compression sets, low temperature properties, density measurement, medium storage, heat aging and O-ring hardness measurements.

[37] Vgl. NAGDI, Khairi: Gummi-Werkstoffe Ein Ratgeber für Anwender, Gupta-Verlag, Ratingen, ²2002, S. 365

[38] BLOBNER, U. und RICHTER, B.: Fachwissen Prüfverfahren für Elastomere: Zugversuch von Ringen (O-Ringe / Rechteckringe) Prüftechnische Grundlagen und wissenswerte Besonderheiten, Ausgabe 12/2014 (Onlineveröffentlichung: http://www.o-ring-prueflabor.de/files/fachwissen-zugversuch-ringe_12_2014.pdf )

[39] BLOBNER, U. und RICHTER, B.: Fachwissen Prüfverfahren für Elastomere: Zugverformungsrestprüfung (ZVR): Prüftechnische Grundlagen und Abgrenzung zur DVR-Prüfung, Ausgabe 06/2014 (Onlineveröffentlichung: http://www.o-ring-prueflabor.de/files/fachwissen_zugverformungsrestpr__fung_06_2014.pdf )

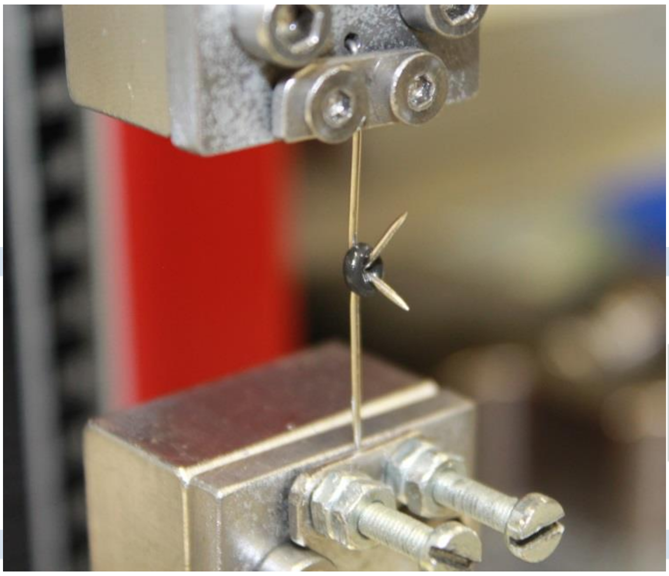

**Fig. 11:** Tensile test of a micro O-ring with special needles as specimen holder

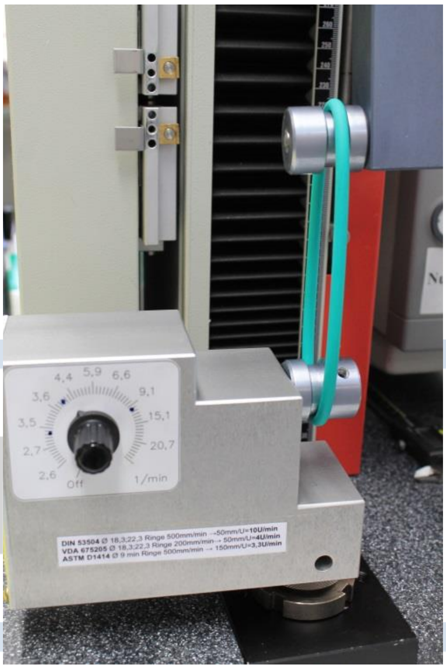


**Fig. 12:** Tensile test of an O-ring on driven rollers according to ASTM D 1414



## 7. O-Rings for High-Tech Applications

The progress of technology in many areas has always been closely linked to the progress of sealing technology. One of the earliest applications of O-rings, as described above, is sanitary engineering. O-rings still play an important role here. The complete domestic installation, heating and solar technology today is based on high-performance O-rings. A service life of considerably more than 50 years under typical operating conditions is possible with a good state of the art.

From the 1930s onwards, the O-ring revolutionized hydraulic applications in airplanes. From there, the O-ring was also used in industrial hydraulics. Today, modern hydraulics are used, for example, for the adjustment of solar collectors in solar power plants or for the operation of wind power plants. Even in many high-performance construction vehicles, the O-ring is used in hydraulics, which is constantly becoming smaller and more powerful. A concrete O-ring application that saves lives is, for example, a hydraulic rescue shear as used by the fire department in accidents.

Likewise, O-rings are almost always used when it comes to further reducing the pollutant emissions of combustion engines or improving the efficiency of engines, e.g. by turbochargers. Many comfort and safety functions (heating/air conditioning, ASR, ESP) are only possible through the use of high-quality and 100% error-free O-rings (e.g. ABS systems). Today, O-rings in modern diesel injection systems are manufactured under ultra-clean conditions,

sometimes cleaned again before assembly and finally installed. Certainly, the introduction of electric vehicles will make certain types of O-rings unnecessary, but modern batteries also require a large number of O-rings, and future mobility should also be comfortable and safe, to which O-rings will contribute.
In process technology, the use of microprocessors and computer-controlled production processes has opened up completely new possibilities, which, however, depend on the reliable display of process states (pressure, temperature, flow rate, pH value, etc.). This requires sensors that have to work safely with O-rings even in a very aggressive environment. Progress in chip manufacturing is also based on ever higher operating temperatures of the O-rings combined with the highest demands in terms of purity and the prevention of the washing out of metal ions. Purity is also important in the manufacture of drugs, and materials technology has not stopped there either. Modern analytical methods such as GC-MS analyses make it possible to find even the smallest amounts of pollutants and to improve materials with regard to the release of critical chemicals.



## 8. Outlook

Even though this simple sealing element is more than 150 years old, it is by no means outdated and is an indispensable part of our everyday life today. O-rings are used in billions of applications. Innovation in technology is hardly imaginable without O-rings and would probably be difficult to afford. They will therefore continue to be an important building block for effective and rapid product development in the future.

If one takes advantage of the progress made in materials technology, process technology, standardization, automation technology and testing technology, it can be assumed that O-rings will continue to be used to meet the coming challenges in sealing technology. The question will be whether it will be possible to exploit the existing potential. And here, special know-how carriers can and must certainly help to ensure that companies are not left behind and miss out on important developments.