# United States Patent [19]

**Telang et al.**

[11] **3,833,321**

[45] **Sept. 3, 1974**


[54] **WEAR-RESISTANT COATING FOR ROTARY ENGINE SIDE HOUSING AND METHOD OF MAKING**


[75] Inventors: **Yeshwant P. Telang,** Grosse Ile; **James C. Uy,** Dearborn Heights, both of Mich.

[73] Assignee: **Ford Motor Company,** Dearborn, Mich.



[22] Filed: **July 5, 1973**

[21] Appl. No.: **376,861**

[52] **U.S. Cl.** .................................... **418/178**

[51] **Int. Cl.** .................................... **F04c 15/00**

[58] **Field of Search** ....... 418/178, 179; 417/DIG. 1; 308/DIG. 8; 29/109.6, 197



[56] **References Cited**

UNITED STATES PATENTS

| | | | |
|---|---|---|---|
| 2,345,975 | 4/1944 | Herman | 418/179 X |
| 3,033,180 | 5/1962 | Bentele | 418/179 X |
| 3,554,677 | 1/1971 | Zapf et al. | 418/178 |
| 3,705,818 | 12/1972 | Grosseau | 418/178 X |
| 3,718,443 | 2/1973 | Faulkner | 29/196.6 |

FOREIGN PATENTS OR APPLICATIONS

| | | | |
|---|---|---|---|
| 724,353 | 2/1959 | Great Britain | 418/178 |



*Primary Examiner*—C. J. Husar
*Assistant Examiner*—Leonard Smith
*Attorney, Agent, or Firm*—Keith L. Zerschling; Joseph W. Malleck


[57] **ABSTRACT**


An improved wear-resistant surface preparation is used on the inner side walls of the combustion chamber of a rotary piston engine. The improvement comprises deposition of two distinct but admixed metallic powders of generally equal hardness; one of the powders contains fluxing agents which enable the deposited powders to self-sinter if deposited in a semi-plastic condition. The powders are deposited on a previously undercut cast iron side housing. The resulting coating composition is characterized by minimum hardness value of $R_c$ 30 at elevated operating temperatures of 400°F. The composition retains a stable hardness at elevated temperature levels up to 1,100°F. The coating may have a porosity of 3–9 percent, but particle size is controlled to limit the porosity to 5 percent which is compatible with lubricating requirements of a rotary engine. The coating composition is deposited across the entire area circumscribed by the path of the outer most side point of the apex seals carried by the rotary piston; the path is substantially commensurate or approaches the entire shape of the epitrochoid chamber. The coating is compatible with the composition of the rotor side seals, oil seals and corner seals bearing thereagainst. The rotor side seals are comprised of cast iron, the oil seals are cast iron coated with limited chromium, the corner seals are prepared from cast iron, and the apex seals are strips of metal coated with an alloy of iron and titanium carbide with graphite.

A method is disclosed comprising: (1) machining a cast side housing structure to a depth sufficient to accommodate a slightly oversized finish coating. The cast structure is undercut, grit blasted and preheated to 200°F., (2) a coating of admixed martensitic stainless steel and an equally hard nickel-based alloy is flame sprayed upon the machined area including approximately ⅜ of an inch margin beyond the undercut area, the spraying being conducted by rotating the surface to be sprayed along with radial and rotative movement of the spray gun arranged to direct the spray perpendicular to the surface, (3) soaking the flame sprayed coating immediately after deposition with oil, and (4) grinding the surface finish to a predetermined reference thickness.


**9 Claims, 5 Drawing Figures**

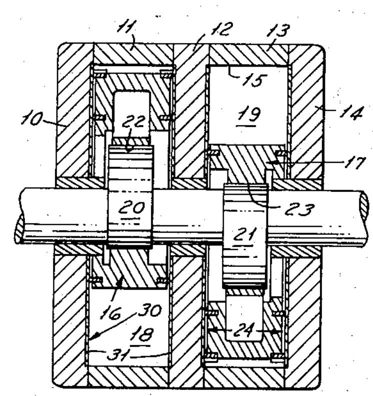


FIG. 1

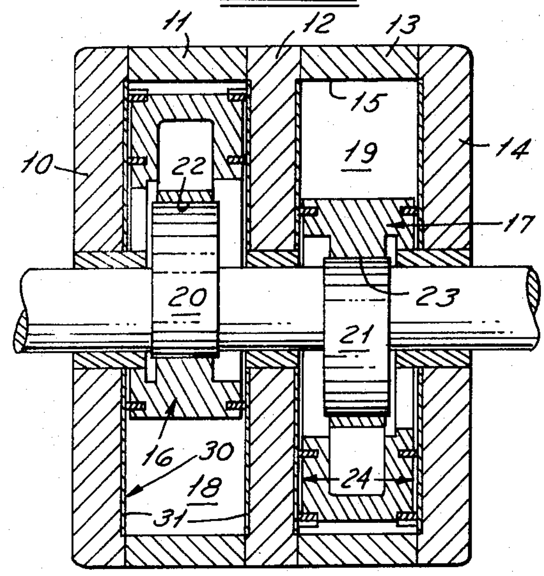



FIG. 2

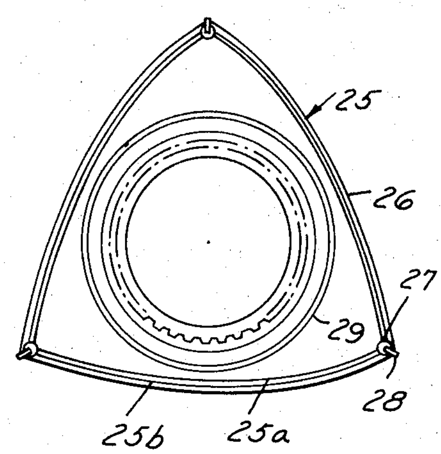



FIG. 4

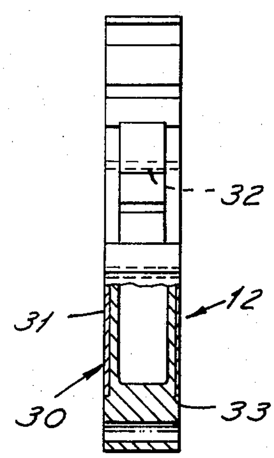



FIG. 3

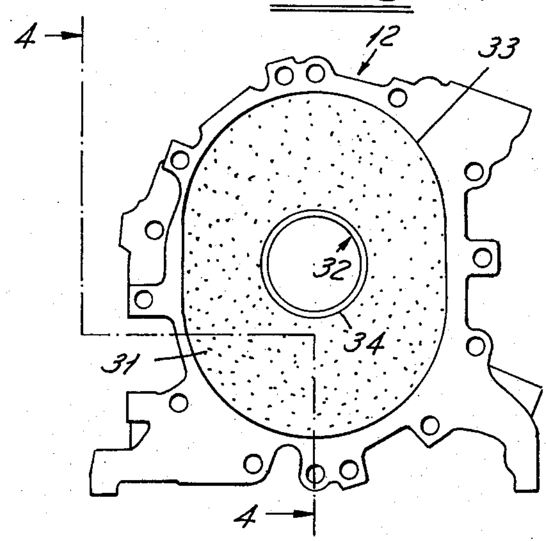
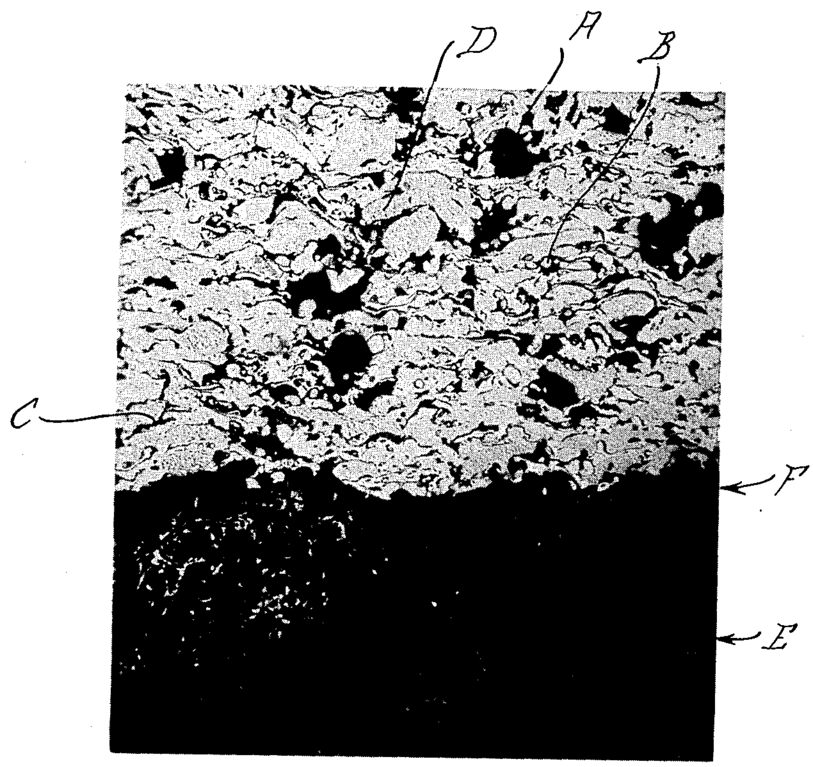



FIG.

FIG. 5.



# WEAR-RESISTANT COATING FOR ROTARY ENGINE SIDE HOUSING AND METHOD OF MAKING

## BACKGROUND OF THE INVENTION

One of the most difficult problems of gas sealing associated with a rotary internal combustion engine is that area between the sides of the triangular shaped rotor and the side housing walls. Certain localities of the side walls experience an extremely hot condition due to the immediate combustion process. It is important that the side seals, as well as the oil seals, ends of the apex seals and corner seals perform with considerable integrity in spite of such adverse conditions.

One commercial approach to the problem of side sealing in a rotary engine is the use of a flame sprayed coating of powdered plain carbon steel. This coating suffers from inadequate wear resistance. Another commercial application uses a plasma sprayed coating of molybdenum on a cast iron side housing. The latter coating is extremely expensive and uncertain in hardness stability at elevated temperatures.

Sprayed coatings of other compositions have been used in applications which do not require high-temperature hardness stability. For example, an admixed preparation of a nickel-chromium-boron alloy powder and a softer metal powder has been used successfully to repair crankshafts because of its high wear resistance at room temperatures. There has been no investigation of the modification of such an admixed coating so that it will effectively retaln its admirable hardness level at elevated temperatures.

Economy plays an important role in the manufacture of a high volume engine. Accordingly, the wear-resistant coatings of the prior art have not been compatible with extremely high rates of production and economy, nor has the required thickness of the coatings been compatible with low cost.

## SUMMARY OF THE INVENTION

A primary object of this invention is to provide a more economical and a much more improved wear-resistant sealing system for a side housing of a rotary internal combustion engine. Most significantly, the invention provides a coating which has improved high-temperature hardness stability.

Still another object is to provide a sealing system which integrates the composition of the rotor side seal, apex seal ends, oil seals and corner seals with the side housing coating composition; the family is compatible with each other to provide unprecedented long-life, efficient sealing characteristics, and accomplishes such goals with a reduced amount of material.

Features pursuant to the improved sealing system comprise control and selection of the admixed powder chemistry to deposit differential particles of generally equal hardness, one of the powders carrying fluxing agents such as silicon and boron, to provide for self-sintering. The particle size of the powders is uniquely controlled to limit porosity of the coating to no more than 5 percent thereby reducing excess lubrication which may chemically break down prematurely and interfere with the efficiency of the engine.

Yet still another object is to provide an improved method of preparing a highly resistant side housing construction for a rotary engine, the method being characterized by flame spraying at lower temperatures an enlarged area of the side housing covering at least that portion equivalent to the silhouette projected by the path of the outermost point of the apex seal of the rotor. The sprayed composition consists of an admixture of a powdered martensitic steel and a nickel-based alloy generally equal in hardness to the stainless steel. The area is ground back to an undercut thickness prior to spraying so that the coating, when fully deposited, projects beyond the finish reference surface; this projection permits grinding off a portion of the finished coating to a degree no less than 5 mils nor more than 15 mils.



## SUMMARY OF THE DRAWINGS

FIG. **1** is a central sectional view of a two rotor, internal combustion rotary engine employing a sealing system embodying the principles of this invention;

FIG. **2** is a side elevational view of a rotor utilized in the construction of FIG. **1**;

FIG. **3** is a sectional view of the side housing element forming a part of the construction of FIG. **1**;

FIG. **4** is a view of the side housing structure shown in FIG. **3** taken along line **4—4**; and

FIG. **5** is a microphotograph, 100× magnification, of the coating composition and depicting the union between the side housing support material and the coating.

## DETAILED DESCRIPTION

Turning now to the drawings, particularly FIG. **1**, the overall engine construction comprises a series of housings including: a left single-walled side housing **10**, a first rotor housing **11**, a center double-walled side housing **12**, a right rotor housing **13** and a right single-walled side housing **14**. The rotor housings **11** and **12** are constructed of die cast aluminum with an appropriate internal wear-resistant coating at **15**; the side housings **10**, **12** and **14** are constructed of cast iron coated with a composition as described herein. A left rotor **16** is disposed in the chamber **18** defined by housings **10**, **11** and **12**; a right rotor **18** is disposed in a chamber **19** defined by housings **12**, **13** and **14**. The rotors are respectively carried by eccentrically mounted shafts **20** and **21**; the shafts extend through respective eccentric openings **22** and **23** in each of the rotors. Each of the rotors are generally triangular in side elevation and have a transverse thickness **24** which is slightly less than the width of the rotor housings.

As shown in FIG. **2**, the rotor carries, on each side thereof, an annular arrangement of side seals **25** which follow the periphery **26** of the rotor. Here, the side seals comprise thin strips **25*a*** and **25*b*** of cast iron (two in number, side by side) which fit loosely within complimentary grooves in the side of the rotor so that seals present a surface for engaging the side housings. Apex seals **28** are carried in transverse slots for engaging the rotor housings; corner seals **27** provide a convenient seal at the juncture of the side seals and apex seals. Circular oil seals **29** surround openings **22–23** and present a surface for sealing against the side housings.

Each of the side housings provide a support or surface **31** for an improved wear resistance coating system **30** which is applied thereover. The support is preferably comprised of cast iron, but includes equivalent materials which have a thermal conductivity of at least 10 BTU/hr./sq. ft./°F/ft. and a yield strength of at least 25,000 psi. The coating system **30** is designed to operate compatibly with the various presented surfaces of the seals carried by the rotor. System **30** is particularly comprised of an admixture of two metallic powder types, each of generally equal hardness, the powders being self-fused upon deposition by a flame spray technique. One of the powder types is comprised of martensitic stainless steel having a chromium content in the range of 12–17 percent, particularly 420 stainless steel having a chromium content by weight of 13 percent. The other powder type is a nickel based alloy having a hardness generally equal to 420 stainless steel. The powder types are admixed in a dry form, the proportion of mixing being preferably on a 1—1 basis. However, the operative range for achieving the broadest object of this invention permits the proportioning to deviate as much as a 4 to 1 ratio of nickel-based alloy to martensitic stainless steel, or a 3 to 1 ratio of martensitic stainless steel and nickel-based alloy.

The nickel-based alloy particularly comprises a small addition of iron, preferably about 5 percent, and important additions of fluxing agents in the form of silicon and boron. The silicon being preferably present in the powder in an amount of about 4 percent and boron being present in the powder in an amount of about 3 percent. The fluxing agents assist in creating the proper amount of hardness and adherency of the particles during flame spraying of the coating. The particles are fed into a flame spray torch, such as an oxy-acetylene gun where the powders are subjected to the gas flame for a time sufficient to melt the outer surface of each of the particles to produce a semi-plastic condition. As a result of the gas flow through the gun, the particles are impelled with sufficient force to impact the surface to be coated and cause a flattened or distorted configuration for each of the particles. Upon congenialing of the surface of each of the particles, a self-fusing effect takes place to provide a rigid and adherent coating. To stimulate the proper amount of melting at the surface of each of the particles, the silicon and boron come out of solution in the particle type (being lower in melting temperature than the other constituents) which effectively stimulates the surface fluid for self-fusing. The silicon and boron come out to form low melting eutectics. The nickel-based alloy may also have a chromium constituent as well as a small amount of carbon, for example 1.0 carbon and 13.25 chromium. As deposited, the resulting composition or coating consists generally of 0.5 percent carbon, 13.25 percent chromium, 37 percent nickel, 1.5 percent boron, 2.5 percent silicon and 45 percent iron. The coating in general consists of a hard martensitic stainless steel matrix and equally hard borides, oxides, carbides and silicides. The oxygen, most importantly, being maintained in the interstitial state within the composition.

As shown in FIG. **5**, the cast iron support E appears darkly shaded, martensitic particle type appear at B as small spheres and the nickel-based alloy particle types appear at D as elongated or flattened particles as a result of impact. Black areas A are pores or voids resulting from controlled spraying, and the light grey stringers C are areas having interstitial oxygen and oxides. Interstitial oxygen is controlled in an amount to assist wear resistance.

An intermediate coating F of aluminum-bronze may be used to promote a metallurgical bond between the support and coating. The intermediate coating should be flame sprayed to a deposited thickness of 1–10 mils.

One of the important phenomenon observed with the use of the above composite coating is its ability to maintain a stable hardness value at high temperatures. For example, at temperatures at 400°F. (typical for the substrate temperature of the side walls of the rotary engine, a minimum hardness has been consistently obtained at $R_c$ **30.** Such hardness level has been observed at even higher temperatures up to 1,100°F. indicating the temperature stability of the coating. This ability to maintain a stable hardness at elevated temperatures is unique and results from a combination of regulated particle chemistry and deposition method. With prior art materials that have been deemed very hard at ambient temperatures, deterioration and loss of sealing efficiency has been observed. The action of the side seals particularly is rigorous. Selected points of the side seals undergo a compound rotary sliding movement against the side housing; other points on the side seals undergo a substantially reciprocating movement similar to the back and forth movement of a knife. Such reciprocating seal movement, when working against the hottest portion of the side housing, (proximate to the peak point of combustion) will cause significant local wear in prior art materials leading to gas leakage. But the coating of this invention exhibits little or no wear under such adverse conditions. During several 100 hour hot/-cold cycling tests of a rotary engine equipped with the coating of this invention, the rotor cleanliness was startingly apparent. There was no combustion deposits observed anywhere on the rotor sides portions disposed between the side seals and oils. Furthermore, wear studies were conducted of four prior art materials which are presently being used for side housing coatings of rotary engines. The engines were run for 100 hours of hot/cold cycling. Prior art material No. **1** consisted of a flame sprayed coating of 1080 steel (thickness 0.015 in.) onto an area of a cast iron side housing (equivalent to the area enclosed by seals) the area outside of the area or projection of the oil seals was induction hardened. Maximum wear after 100 hours was 0.00135 inch. Prior art material No. **2** and No. **3** consisted simply of a sprayed steel 1080 and 10100 coating (thickness 0.015 in.) on the entire side housing; measured wear was 0.0047 and 0.0055 respectively. Prior art material No. **4** was a salt bath nitrided surface with a case depth of 0.0002 inch; the measured wear was 0.0008 inch. In contrast three modes of the inventive coating (1:1 ratio of 420 stainless steel and nickel-based alloy) were tested; the prior art material showed 2–5 times more wear. First a 15 mil coating of the inventive material was sprayed over an intermediate coating of bronze; the measured wear was 0.0003 inch. Secondly, an 8 mil coating of the inventive material was deposited without an intermediate coating; measured wear was 0.00025 inch. Thirdly, a thin coating of the inventive material was used, the coating not being immersed in oil after deposition and not lapped; measured wear was 0.00022 inch.

One discovered characteristic that a side housing surface treatment should possess is that of limited porosity. Although the coating of this invention is operative with a porosity of 3–9 percent, 5 percent or less is preferred to prevent unwarranted lubricant break-down. A micro-thin lubricating film between the seals and the side housing is desirable; this is best maintained by a slightly porous metallic coating on the seals and side housing whereby the porosity can act as a reservoir or supply to maintain the film. But too much porosity interferes with the effeciency of the rotor by creating a viscous drag and allowing excess lubricant to be broken down by the combustion process leaving deposits. This invention teaches that a preferred porosity of 5 percent or less can be achieved by controlling the grain size of the admixed particle types being fed to the spray gun. No greater size particle that will pass a 200 mesh should be used, preferably −200, +325.

A preferred method for carrying out the invention comprises:

1. Substrate Surface Preparation

The cast iron side housing, after having been cast, is milled to provide a reference surface across the entire area **31** defined between the projection of the outer most point of the apex seals (as they undergo planetary movement) and the inter periphery defined by the eccentrically mounted portions **22** and **23.** The milled surface is then subjected to an undercut treatment to accommodate an oversized finish coating. The undercut is provided with a 30° chamfer at edges **33** and **34** to assist in providing a more adherent joint with the cast iron substrate. Overspray, immediately adjacent to the edges of the center hole is avoided by leaving unsprayed a margin **32** of about 0.05 inches at the inter periphery **34.** The undercutting treatment is adapted to provide a metal finish of 64–256 micro inches. The undercut side housing is then cleaned by hot degreasing, and grit blasted with **24** grit crushed iron at 70 psi air pressure. The grit blasting is carried out with a lower air pressure than normal so as to provide a better knurled surface. The side housing is then preheated to about 200°F. in preparation for the spraying step.

2. Flame Spraying

Areas of the housing that are not to be coated are masked, although the overspray will be only approximately 0.25–.37 of an inch. A preferred powder mixture, on a 50–50 basis, consists of 420 stainless steel and a nickel-based alloy having a chemical content of 13 percent chrome, 5 percent iron, 4 percent silicon and 3 percent boron, 0.75 percent carbon, 75 percent nickel. The admixed powders are introduced to a flame spray gun utilizing the oxy-acetylene principle. Flame spraying, in its most general sense, is known as metallizing which is a process of spraying molten metal onto a surface to form a coating. Pure or alloyed metal or a mixture of metals is melted in a flame; a blast of compressed air breaks up the molten metal into a fine spray. The deposit of this spray builds up on a substrate to form a coating having physical properties which are different from the constituent metals. Sprayed metal is generally porous, harder and more brittle. The porosity and higher hardness generally contributes to wear-resistance of bearing surfaces. Thus flame spraying is commonly used for building up worn parts.

For purposes of this invention, the hardness of the deposited coating has been increased over that known before, the porosity has been limited for advantageous purposes and the costs of deposition have been reduced.

The acetylene pressure is set preferably at 15 psi and the oxygen pressure at 24 psi. The flow of each gas constituent is preferably set at 30 percent for acetylene and 70 percent for oxygen. It is further preferred that the surface to be sprayed is maintained in a vertical position in order to avoid entrapping dust. More importantly, the oxy-acetylene gun should be maintained at a perpendicular orientation with respect to the plane of the surface to be coated. The housing is rotated on its own axis, while at the same time, the gun is reciprocally moved so as to shift radially with respect to the housing section being sprayed. The tip of the gun is placed approximately 10 inches from the surface to be coated and the housing is usually rotated at a speed of about 60 rpm.

The thickness of the coating is controlled in a range of 0.02 inches to 0.03 inches, preferably 0.025 inches thereby allowing for 0.01 inch removal of the coating in a subsequent step of the process.

3. Finishing of Spray Coating

Immediately after the flame spray deposition, the coating is subjected to an application of engine oil such as 10 *w* 30 while the housing is still hot. Enough oil is applied to soak the coating. Thereafter, the coated surface of the housing is ground to a finish size so as to be even with the reference surface determined in a prior step as a milled surface. The resultant coating thickness is about 0.015 inches after grinding. The housing surface is lapped (utilizing free grinding powder) to a finish of 10 micro inches on the cast iron and 20/30 micro inches on the spray coating, this discounts readings due to pores. Finally, the housing surface is ultrasonically cleaned, rinsed and oiled before use of the housing in engine operation.

Important features of the method comprise the flame spray deposition across the entire area of the side housing, almost commensurate with the epitrochoid configuration of the rotor housing. The disposition of the spray gun, relative to the surface to be coated, has been found to require close adherence to the teaching herein in order to obtain the metallurgical characteristics sought. The admixed powders are subjected to a flame spray temperature which is somewhat lower than that heretofore used by the prior art so that oxides and interstitial oxygen is controlled. The coating is applied to a subsurface which has been undercut and chamferred to provide an improved adherent effect.

To provide an improved metallurgical bond between the coating and the support, an intermediate coating of aluminum bronze may be spray coated in a thickness range of 1–10 mils.

We claim:

**1.** In a rotary engine, the combination comprising:

a. means defining a combustion chamber having an epitrochoidally shaped end wall and flat side walls, the side walls having at least one portion thereof coated with a wear resistant composition consisting of a composite of martensitic stainless steel and a nickel-based alloy having a stabilized hardness of at least 30 $R_c$ at engine operation temperature,

b. a polygonal shaped rotary piston having two or more apexes, the piston is supported for rotation on an eccentric shaft for moving in a planetary motion within said chamber, said piston carrying at least one annular arrangement of side seals on each side thereof, the seals being resiliently biased into continuous contact with a side wall of said chamber.

**2.** The combination as in claim **1,** in which said rotor also carries at least one annular oil seal on each side thereof and lying radially inwardly of said side seal, said oil seal and side seal each being comprised of cast iron and at least one of said seals having a chrome coating over said cast iron, said seals being effective to continuously engage said side wall coating.

3. In a side wall construction for a rotary piston internal combustion engine, the improvement comprising:

a. a side wall support presenting a flat surface bounded by an epitrochoid periphery and a circular inner periphery,

b. a wear-resistant coating comprised of a mixture of generally equally hard particle types, one particle type consisting of martensitic stainless steel and the other particle type consisting of a nickel-base alloy, said coating being self-fused across the entire area of said surface, said coating having a deposited hardness of at least Rockwell C 30 at a temperature level of at least 400°F.

4. The improvement as in claim 3, in which said coating has a thickness in the range of 0.02 to 0.03 inch.

5. The improvement as in claim 3, in which the porosity of said coating at the outer face of said coating is in the range of 3–9 percent, and oxygen is present in said coating in the form of interstitial oxygen.

6. The improvement as in claim 3, in which all particles are sized no less than 200 mesh whereby porosity is controlled.

7. The combination as in claim 3, in which the side wall supporting said coating is characterized by a thermal conductivity of at least 10 BTU/HR/sq. ft./°F/ft. and a yield strength of at least 25,000 psi.

8. The improvement as in claim 3, in which said support is comprised of cast iron.

9. The improvement as in claim 8, in which a coating of aluminum bronze in the thickness range of 1–10 mils is flame sprayed between said wear-resistant coating and said support surface.

* * * * *