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(54) **Camshaft assembly**

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- **DATABASE WPI Week 9209, Derwent Publications Ltd., London, GB; AN 92-065693 & DD-A-294 317 (VEB KERAMISCHE HERMSDORF) 29 September 1991**

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Description

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to a camshaft assembly used in a valve train such as an internal combustion engine.

2. Description of the Prior Art

In recent years, fuel cost savings have become an important issue in the automobile industry due to the need to save natural resources and conserve the global environment. One approach toward this goal is to improve the thermal efficiency of automobile engines by making car bodies more lightweight and running engines on leaner fuel mixtures, while another is to reduce mechanical losses in engines. Current methods now being studied to reduce mechanical losses in the valve train systems of an engine are mainly directed toward making parts more lightweight with a view to reducing their inertial mass, and reducing frictional torque due to sliding.

FIG. 1 shows different valve trains used in engines. In the figure, A shows a direct drive system, B a swing arm system, C a rocker arm system and D a projecting rod system. "OHC" and "OHV" represents "overhead camshaft" and "overhead valve", respectively. Of these valve trains, the OHC system is most widely used due to its excellent valve movement characteristics from the viewpoint of engine performance.

FIG. 2 is a horizontal section of a typical OHC direct drive valve train. In FIG. 2, reference numeral 1 is an engine cylinder head, 2 is a cam, 3 is a valve lifter, 4 is a cam follower, 5 is an intake/exhaust valve, 6 is a valve seat, and 7 is a valve spring. In FIG. 2, the valve lifter 3 is driven by the cam 2 so as to transmit the displacement of the cam 2 to the intake/exhaust valve 5.

As can be seen from FIG. 2, the cam and cam follower possess surfaces which slide against each other. The contact pressure between these surfaces is extremely high, and particularly, under engine running conditions in the low engine speed region such as when the engine is running idle, this sliding occurs when a lubricant oil film has not completely formed. Consequently, the frictional losses due to the action of the valve train represent a significant proportion of the total frictional losses in the engine which cannot be ignored. Further, as lubrication is inadequate, cam damage due to wear, scarfing and pitching is a serious problem.

Recently, multi-valve systems and variable valve timing mechanisms have been used in an effort to improve intake/exhaust efficiency in automobile engines, however due to increasing spring loads, and to the fact that sufficient cam width cannot be maintained to accommodate these mechanisms in the narrow space of a cylinder, they lead to an increase of cam/cam follower contact stress. This causes a decrease of the oil film thickness formed on the sliding surfaces, resulting in increased frictional torque and cam damage.

To deal with this problem, a method to reduce friction and wear has been proposed by constructing the cam follower in the form of a roller free to rotate about a center axis, so that the friction in the sliding process is mainly rolling friction as is disclosed for example in Tribologist, Vol.31, No.11 (1991), pages 855-859. Other attempts consist in constructing the cam of high strength, lightweight ceramic materials such as is described in Japanese Patent Application Laid-Open No.59-34409, page 1, right-hand column, line 13 - page 2, upper left-hand column, line 1, so as to reduce inertial mass and confer anti-wear properties. However, this may lead to increased cost as the mechanism is more complex, and as the ceramic material is insufficient in mechanical compatibility with the metal piece with which it is in contact, the metal suffers increasing abrasion by the ceramic material leading to serious wear and damage.

A method is disclosed on page 2 of Japanese Patent Application Laid-Open No. 5-340212 wherein an adjusting shim is made of a ceramic material and has a surface layer which consists of a different composition to that of the base material and has a low hardness. In such an adjusting shim, compatibility between the ceramic adjusting shim and a cam is improved by the wearing of the surface layer in the initial stages of sliding, so that the power used to drive the camshaft can be reduced. As the adjusting shim is offset with respect to the cam and is free to rotate, wear does not generally occur selectively in one part of the sliding surface of the shim. On the other hand, the nose of the cam is subjected to the most load, and is therefore more easily damaged. There is therefore a possibility that the surface smoothness of the nose may decline in use compared to that of the adjusting shim.

A journal piece 9 of the camshaft consists of a bearing which supports a camshaft 8 such that the latter is free to rotate, as shown in FIG. 3. Although the journal piece 9 is not subject to conditions as severe as the sliding conditions existing between the cam and cam follower, the journal piece 9 is nevertheless in Hertzian elastic contact with other parts. In general, this means it is subject to a high contact stress, and as it is also a sliding bearing, it may be considered as a sliding member which has to withstand rigorous conditions. However, the reduction of friction and wear of the journal piece in a camshaft has still not been studied in depth.

SUMMARY OF THE INVENTION

An object of the present invention is to provide a camshaft assembly which solves conventional problems inherent in such assemblies. This is achieved by reducing frictional losses due to sliding, permitting considerable reduction of power loss, and preventing damage of a cam and cam follower due to sliding.

In order to achieve the above object, this invention provides assembly as set forth within the scope of the appended claims, the camshaft assembly comprising a metal camshaft, a cam piece constructed of a ceramic material, a cam follower and a cam journal piece. The surface roughness of the cam piece is not greater than 0.1 μm in terms of center-line mean roughness (Ra) defined in JIS (Japanese Industrial Standard) and the Vickers hardness of the cam piece is not less than 1000 kg /mm^2. Throughout the specification and Claims, surface roughness is indicated in terms of the center-line mean roughness (Ra) unless otherwise specified.

In the camshaft assembly of the present invention, the cam journal piece is also preferably constructed of a ceramic material.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a descriptive drawing of various valve trains used in an engine.
FIG. 2 is a vertical section of a direct drive valve train.
FIG. 3 is a perspective view of a cylinder head.
FIG. 4 is a graph showing the relation between oil film thickness ratio and frictional coefficient (cast iron-steel).
FIG. 5 is a descriptive drawing of a roller-chip friction testing apparatus.
FIG. 6 is a graph showing friction test results.
FIG. 7 is a descriptive drawing of a camshaft.
FIG. 8 is a conceptual drawing of a motoring test device.
FIG. 9 is a graph showing endurance test results. The asterisk (*) in the figure denotes a comparative example.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Summarizing the essential features of this assembly of the present invention, the cam piece is constructed of a ceramic material, the cam follower and/or cam journal piece preferably also being constructed of a ceramic material. These ceramic members are provided on a shaft consisting of a metallic base material, the surface roughness of the sliding surfaces not exceeding 0.1 μm in terms of Ra.

It is moreover to be preferred that the ceramic material has a modulus of longitudinal elasticity of not less than 25000 kg /mm^2, and a Vickers hardness of not less than 1000 kg /mm^2.

In the camshaft assembly of this invention, the cam piece and journal piece, which slide on the camshaft, may be monolithic ceramic sintered bodies provided that their properties lie within the specified ranges, and they may also consist of ceramic materials reinforced with fibers, whiskers or particles of nanometer size, i.e., having an average particle size of less than 1 μm (hereinafter referred to as "nanoparticles").

Examples of monolithic ceramic sintered bodies are oxides such as alumina, zirconia, mullite and spinel, nitrides such as silicon nitride, aluminum nitride and titanium nitride, carbides such as silicon carbide and titanium carbide, boron compounds such as boron nitride and boron carbide, and silicides such as titanium silicide. Examples of composite materials are long-fiber reinforced composite materials such as alumina, silicon nitride or crystallized glass reinforced with carbon fiber, silicon carbide fiber, alumina fiber or TYRANNO FIBER (trade name, produced by Ube Industries, Ltd.), whisker-reinforced composite materials such as alumina or silicon nitride reinforced with silicon carbide whiskers, or particle dispersion-reinforced composite materials such as silicon nitride or alumina reinforced with particles of titanium nitride or silicon carbide having a micron size or nanometer size.

When the camshaft of this invention is used, it is found that the camshaft drive torque, that is, frictional losses between the cam and cam follower, and in the bearings, are largely reduced, and kinetic losses in an internal combustion engine are reduced. Further, wear and damage to the cam and cam follower due to sliding, that is, scarfing wear of the cam and cam follower, are remarkably lessened.

In a valve train of an internal combustion engine such as an automobile engine, the mechanism is generally lubricated. In the ideal case, a state of fluid lubrication exists, and there is preferably no solid contact between sliding surfaces due to the formation of an oil film.

In the case where one surface was steel and the other was cast iron, the inventors found the relation shown in FIG. 4 between the film thickness ratio and the frictional coefficient, the film thickness ratio being defined as the ratio of the minimum oil thickness determined by the sliding conditions to the root mean square of the surface roughness of the contact surfaces. The film thickness ratio is therefore given by the relation:
Equation 1:

$$\text{Film thickness ratio} = \frac{\text{Minimum oil film thickness}}{\text{Surface roughness of sliding surfaces in contact}} \quad (1)$$

The minimum oil film thickness is given by the expression $2.65 \times R \times U^{0.7} \times G^{0.54}/W^{0.13}$, where R is the diameter of a roller 11, U is a speed parameter, G is a material parameter and W is a load parameter in the roller-chip friction test shown in FIG. 5. The surface roughness of the sliding surfaces in contact is given by the expression $(R_1^2 + R_2^2)^{0.5}$ where R_1 is the chip surface roughness (Ra), and R_2 is the roller surface roughness (Ra).

The region where the film thickness ratio is not more than 1 is a boundary lubrication region, whereas the region where the ratio is not less than 3 corresponds to complete fluid lubrication with low friction. The region of more than 1 to less than 3 is considered to be a mixed lubrication region intermediate between boundary lubrication region and fluid lubrication region.

The proportion of mechanical losses in an automobile engine due to losses in the valve train system is greatest under the idle engine running conditions and it accounts for 20 - 25% of the total losses. In FIG. 4, the region corresponding to idle engine running conditions is the boundary lubrication region where the film thickness ratio is of the order of 0.1 - 1. It is therefore evident that in order to reduce frictional losses, the lubrication state should be arranged to be as close as possible to the fluid lubricabion state, that is, the film thickness ratio should be increased.

In the case of a cast iron cam-steel adjusting shim assembly where the sliding surfaces were mirror-surface polished, measurement of the camshaft drive torque showed a reduction of 5% due to the polishing, however in endurance tests where the engine was operated continuously, the camshaft drive torque was found to increase with the elapsed time.

In particular, observation of the cam and cam follower surfaces after sliding showed that the smoothness of the cam nose had declined, and that it was partly burnt. It was concluded that since the cam nose is the part of the cam where the thickness of the oil film is smallest, the surface smoothness first increases due to repeated solid contact between minute projections on the contact parts, but this leads to a decrease of oil film thickness and finally results in a deterioration of surface smoothness in comparison to the initial stage. This was considered to be responsible for the increase of the camshaft drive torque.

After more detailed studies, it was found that when the Vickers hardness of the ceramic cam piece was less than 1000 kg /mm^2, the surface roughness and particularly the surface roughness of the nose of the cam piece increased as a result of wear due to abrasion by the cam follower. In some cases local wear occurred which caused the clearance between the cam piece and the cam follower to vary, thereby increasing frictional resistance even further. It was moreover found that when this situation persisted, it sometimes led to burning and caused cam scarfing damage. It is therefore preferable to use a cam piece having a Vickers hardness of not less than 1000 kg /mm^2.

As the contact surface pressure between the cam and cam follower increases in the low engine speed region including the case when the engine is running idle, the cam piece and cam follower undergo elastic deformation. When a material of low Young's modulus is used, the extent of this deformation increases, the contact surface area increases as in the case when the surface roughness of the sliding surfaces increases, and the sliding frictional resistance increases.

From the above considerations, it was found that the camshaft driving torque could be reduced by constructing the cam piece in the camshaft assembly, and more preferably also the journal piece, of a ceramic material. The surface roughness Ra of these ceramic members does not exceed 0.1 μm.

By constructing the sliding parts of the camshaft assembly from a ceramic material, the weight of the camshaft assembly can be reduced. The valve spring load and the load on the journal bearing can therefore be reduced, and sliding frictional resistance can be reduced.

Moreover, by constructing one of the sliding surfaces from a ceramic material, the frictional coefficient can be reduced in comparison to the conventional case where both surfaces were constructed of metal. This is considered to be due to the fact that as the joining of a ceramic surface to a metal surface is generally different to that of two metal surfaces, the surface activity in solid friction is low, and cohesion due to mutual interactions is also low.

According to a preferred embodiment of this invention, by arranging that the Vickers hardness of the sliding surface of the ceramic material used in the camshaft assembly is not less than 1000 kg /mm^2, and the modulus of longitudinal elasticity of same is not less than 25000 kg /mm^2, the increase of frictional resistance due to material factors which occurred in a cast iron cam - steel cam follower can be suppressed. Further, due to the hardness of the ceramic material, the initial surface roughness of the ceramic sliding surface can be maintained, and there is consequently no deterioration of the conditions which were initially set without causing deterioration of the ceramic due to increase of frictional resistance.

In the case where a ceramic member slides on a metal member, there is a problem with regard to possible attack by the ceramic sliding member on the metal sliding member. In particular, in the case of the camshaft of this invention, low friction is achieved by controlling the oil film thickness ratio. There is therefore a risk that if the oil film thickness were to decrease below its initial value due to deterioration or loss of lubricating oil when the oil film thickness ratio is low, as during idle engine running conditions for example, the ceramic member may attack the metal member so as to increase the surface roughness, and as a result the sliding frictional resistance may increase. However, in the camshaft assembly

of this invention, it was found that if the surface roughness Ra of the cam piece and the journal piece do not exceed 0.1 μm, the surface roughness of the other member does not increase even in the boundary lubrication region where there is solid contact between the two members.

More preferably, attack on the other member is further reduced by arranging that the surface roughness Ra of the ceramic member does not exceed 0.05 μm.

In the cam piece/cam follower of the camshaft assembly of this invention, if the surface roughness Ra of the sliding surfaces in contact does not exceed 0.1 μm, sliding frictional resistance is reduced in comparison with a conventional valve train. This is considered to be due to a corresponding increase of the oil film thickness ratio during idle engine running conditions under which problems most likely arise, thereby reducing solid contact between the sliding surfaces so that an excellent reduction of frictional losses is brought about.

More preferably, an enhanced reduction of frictional losses may be achieved by arranging that the surface roughness Ra of the sliding surfaces does not exceed 0.05 μm. This is considered to be due to an increase of the oil film thickness ratio on the characteristic curve of oil film thickness ratio versus frictional coefficient shown in FIG. 4, resulting in an increased proportion of fluid lubrication.

As the engine becomes more efficient the mechanism in the cylinder head becomes more complex, and since this mechanism has to be accommodated within a confined space, insufficient space is available for the cam width. If the cam is constructed of a metal such as cast iron which has a small burn load per unit cam width, the spring load must be decreased, hence the engine speed at which surging occurs decreases and engine efficiency decreases. However, the camshaft assembly of the present invention can be used with a contact pressure of 20 kg /mm per unit width in terms of linear load. Therefore, the spring load is the same as in the prior art so that an engine may be provided which can be used up to a high revolving speed region.

Surging of the valve spring occurs in the high engine speed region. This is due to the fact that the valve spring sets up resonance in the high engine speed region, causing the cam follower to collide with the cam at a high speed. As a result, the use of the camshaft in the high speed region presented a problem with regard to damage and service life. In order to obtain a cam with high reliability over a wide range including dangerous engine speeds (normally 6000 rpm and above), it is therefore preferable to use a material which can withstand high speed collisions. Studies of materials able to withstand surging showed that a ceramic material according to this invention having a bending strength of not less than 120 kg /mm^2 in terms of the 3-point bending strength according to JIS R1601 was also capable of withstanding collisions.

Such a material may be obtained by forming a fine-grained crystalline matrix having an average grain size of not more than 10 μm, or by dispersing a second phase, having an average particle size less than that of the average grain size of the matrix phase, in the grain boundaries of the matrix grains or within the matrix grains, or by a combination of thereof. Preferably, the average grain size of the crystalline matrix phase expressed in terms of linear density is no less than 35 grains per 30 μm. The linear density as referred to herein is the number of crystalline grains passing an arbitrary 30 μm line on an arbitrary observation surface in the ceramic material. It is thought that by forming the fine-grained matrix phase during combining the matrix phase and the second phase, many more crystal grains or particles and grain boundaries will be involved when a split due to impact stress advances by unit length, and the impact stress is relieved, thereby increasing the initial energy required to rupture the material. Further, it is thought that by dispersing a second phase, pinning or diffraction of cracks occurs so that the material has increased resistance to rupture.

More preferably, when the material used for the cam piece has a strength not less than 150 kg /mm^2, even greater reliability with regard to surging is achieved. Such a material may be obtained by grain-refinement, or by reinforcement with precipitation or dispersion of nanoparticles which have nanometer size diameter. This imparts a further increased impact resistance to the material and provides an increased reliability at super-high engine speeds.

This invention will now be described in more detail by means of the following embodiments.

Example 1

The roller chip friction test of FIG. 5 was performed using various ceramic chips and a Cr-Mo steel roller. The test apparatus was provided with a chip 10, roller 11 and test support 12. The properties of the materials tested are shown in Table 1. In the test, the frictional coefficient was measured taking the film thickness ratio as a parameter by varying the sliding conditions and surface roughness. The oil film thickness ratio was calculated by means of Equation (1) as described hereintofore.

FIG. 6 shows the results. In the figure, No. 6 chip is constructed of cast iron, No. 2 is zirconia, No. 1 is alumina, No. 4 is silicon nitride reinforced by a silicon carbide whisker dispersion, No. 5 is silicon nitride reinforced by a dispersion of 80 nm particles of silicon carbide, and No. 3 is commercial silicon nitride. The asterisks (*) in the figure indicate comparative examples. In the case of all materials, it was found that the frictional coefficient decreased with increase of the oil film thickness ratio. Further, the frictional coefficients were in the following order:
cast iron > zirconia > alumina > silicon nitride reinforced with a dispersion of silicon carbide whiskers > silicon nitride

reinforced with a dispersion of silicon carbide nanoparticles > silicon nitride.

It is seen that use of these ceramic materials reduced the frictional resistance of the sliding parts in comparison to the case when cast iron was used.

Table 1

Ceramic Chip used in Test

No.	Material	Vickers hardness (kg /mm^2)	Modulus of longitudinal elasticity (Kg /mm^2)	Strength (kg /mm^2)
1	alumina	1900	33000	40
2	zirconia*1	1500	20000	110
3	silicon nitride	1600	32000	100
4	silicon carbide whisker-silicon nitride*2	2000	34000	130
5	silicon carbide particle-silicon nitride*3	2400	35000	135
6	cast iron*1	900	20400	-

Notes

1) *1: Comparative examples
2) *2: Silicon nitride reinforced with a dispersion of silicon carbide whiskers
3) *3: Silicon nitride reinforced with a dispersion of silicon carbide nanoparticles

Next, a roller-chip friction test was performed using a Cr-Mo steel roller having a surface roughness Ra of 0.1 μm, and chips constructed of the materials as shown in Table 1 with different surface roughnesses. After the test, the surface roughness of the Cr-Mo steel roller was measured. The roller speed was 300 rpm, and the chip was allowed to slide on the roller with oil lubrication for a period of 5 minutes. Table 2 shows the results. It is seen that by arranging that the surface roughness Ra of the chip does not exceed 0.1 μm, the surface roughness of the Cr-Mo steel roller after the test was of the same order as or less than its roughness Ra, i.e. 0.1 μm before the test,. This shows that reducing the surface roughness of the ceramic material, reduces its degree of attack on the other material with which it is in contact.

Table 2

Surface Roughness (Ra) of Roller after Test [μm]

No.	Material	0.5μm*1	0.1μm	0.05μm	0.03μm
1	alumina	0.42	0.12	0.12	0.13
2	zirconia*1	1.67	0.87	0.54	0.24
3	silicon nitride	0.27	0.09	0.09	0.11
4	silicon carbide whisker-silicon nitride*2	0.34	0.11	0.12	0.11
5	silicon carbide particle-silicon nitride*3	0.37	0.12	0.13	0.12
6	cast iron*1	1.53	0.81	0.38	0.19

Notes

1) *1: Comparative examples
2) *2: Silicon nitride reinforced with a dispersion of silicon carbide whiskers
3) *3: Silicon nitride reinforced with a dispersion of silicon carbide nanoparticles

Example 2

The camshaft assembly of FIG. 7 was constructed using a cam piece formed from each material shown in Table 1, and a cast iron camshaft 8. The contact surfaces of the cam piece 2, journal piece 9, cam follower and bearing of the camshaft 8 were surface-finished under various conditions so as to provide the surface roughnesses Ra of 0.5 μm, 0.1 μm, 0.05 μm and 0.03 μm as shown in Table 3 - Table 5.

Each of thus prepared camshaft assemblies was rotated by the motoring device, shown in FIG. 8 and equipped with a direct drive OHC valve train (cylinder head). This mortaring device was used in a commercial 2000 cc automobile gasoline engine. The cam drive torque was measured at rotation speeds of 500, 1500 and 3000 rpm in terms of engine speed. The same test was performed using a conventional camshaft assembly equipped with a cast iron cam piece and journal piece. The cam drive torque reduction efficiency of each camshaft assembly for each ceramic material or cast iron shown in Table 3 - Table 5 was computed using the following Equation (2):

Camshaft torque reduction efficiency = [1 - {(camshaft torque of camshaft using ceramic material)/camshaft torque of conventional cast iron camshaft)}] x 100 (%).

These results are shown in Table 3 - Table 5. From the results of Table 3 - Table 5, it is evident that when the camshaft assembly of this invention was used, a large reduction of camshaft torque was obtained due to the reduction of sliding friction resistance compared to the case when cast iron was used.

Table 3

Camshaft Torque Reduction Efficiency (%) after Test at 500 rpm

No.	Material	Surface roughness of contact surface (Ra) 0.5μm*1	0.1μm	0.05μm	0.03μm
		Camshaft Torque Reduction Efficiency (%)			
1	alumina	7.2	13.8	15.3	17.3
2	zirconia*1	2.1	3.4	4.8	5.6
3	silicon nitride	12.1	15.4	17.3	19.2
4	silicon carbide whisker-silicon nitride*2	8.3	14.4	16.2	18.5
5	silicon carbide particle-silicon nitride*3	7.7	14.1	16.0	18.8
6	cast iron*1	Reference	2.2	3.3	4.2

Notes

1) *1: Comparative examples
2) *2: Silicon nitride reinforced with a dispersion of silicon carbide whiskers
3) *3: Silicon nitride reinforced with a dispersion of silicon carbide nanoparticles

Table 4

Camshaft Torque Reduction Efficiency (%) after Test at 1500 rpm

No.	Material	Surface roughness of contact surface (Ra) 0.5μm*1	0.1μm	0.05μm	0.03μm
		Camshaft Torque Reduction Efficiency (%)			
1	alumina	6.4	9.3	12.3	15.1
2	zirconia*1	2.4	3.8	4.5	6.2
3	silicon nitride	11.1	13.8	16.2	18.1
4	silicon carbide whisker-silicon nitride*2	9.8	11.4	14.6	16.8
5	silicon carbide particle-silicon nitride*3	9.4	11.2	14.5	16.6
6	cast iron*1	Reference	2.6	3.5	4.3

Notes

1) *1: Comparative examples
2) *2: Silicon nitride reinforced with a dispersion of silicon carbide whiskers
3) *3: Silicon nitride reinforced with a dispersion of silicon carbide nanoparticles

Table 5

Camshaft Torque Reduction Efficiency (%) after Test at 3000 rpm

No.	Material	Surface roughness of contact surface (Ra) 0.5μm*1	0.1μm	0.05μm	0.03μm
		Camshaft Torque Reduction Efficiency (%)			
1	alumina	6.2	9.3	12.1	15.1
2	zirconia*1	2.7	3.8	4.6	5.6
3	silicon nitride	11.5	14.1	16.8	18.5
4	silicon carbide whisker-silicon nitride*2	10.6	12.0	15.1	17.2
5	silicon carbide particle-silicon nitride*3	10.2	11.6	15.0	16.9
6	cast iron*1	Reference	2.5	3.6	4.1

Notes

1) *1: Comparative examples
2) *2: Silicon nitride reinforced with a dispersion of silicon carbide whiskers
3) *3: Silicon nitride reinforced with a dispersion of silicon carbide nanoparticles

For the case of silicon nitride in the examples, a camshaft was assembled wherein the journal piece was also constructed of a ceramic material. The torque reduction efficiency compared to the conventional case of cast iron was measured when the camshaft was incorporated in the motoring device shown in FIG. 8, and operated at 500 rpm. As shown in Table 6, it was found that the torque reduction efficiency when the journal piece was also constructed of a ceramic material was further improved compared to the case of a camshaft wherein only the cam piece was constructed of a ceramic material, as shown in Table 6.

Table 6

Camshaft Torque Reduction Efficiency (%) after Test

Form of Cam Shaft Assembly	0.5μm*	0.1μm	0.05μm	0.03μm
Only cam piece constructed of ceramic material	12.1	15.4	17.3	19.2
Cam piece and journal piece constructed of ceramic material	14.2	17.6	20.1	23.4
Cast iron construction*	Reference	2.2	3.3	4.2

The asterisk (*) indicates a comparative example.

Example 3

Of the camshaft assemblies specified in Example 2, the camshaft assembly provided with the silicon nitride cam of No. 3 in Table 1 was operated continuously for 200 hours at a rotation speed of 1500 rpm using the same motoring device as that of Example 2. In the test, the surface roughness Ra of the sliding surfaces in contact was 0.05 μm, and the reduction efficiency was measured compared to the camshaft drive torque when the cast iron cam of the comparative example in Example 2, Table 4, was used, the surface roughness of the sliding surfaces Ra of the cast iron cam being 0.5 μm. A trial run was performed before carrying out the measurement in order to achieve initial compatibility of the sliding surfaces.

As shown in FIG. 9, the torque reduction efficiency decreases with time in the case of the conventional cast iron cam, but in the case of the present inventive example, there is substantially no change of the torque reduction efficiency for the entire duration of the test. This shows that the reduction of frictional losses in the valve train of the camshaft assembly of this invention is sustained for a long time period. In other words, the initial torque reduction achieved with the camshaft assembly of the present invention continues for a long time, and the effect of the surface roughness which was initially set is maintained. In FIG. 9, the asterisks denote comparative examples.

When the sliding surfaces were observed after the test, the cam nose in particular was found to be rough in the case of the conventional cast iron cam. It appeared that this roughening caused a decrease of the oil film thickness ratio, leading to an increase of the camshaft drive torque.

Example 4

The tendency of a valve operating system to burn was examined when the contact load for the case of maximum cam lift was varied by varying the spring coefficient of the valve springs in the system. In this test, the torque meter was removed from the device shown in FIG. 8, the rotation speed was set at 1000 rpm, and the contact load was varied. Only the cam piece of the camshaft assembly was constructed of a ceramic material, the surface roughness of the sliding surfaces in contact being 0.05 μm Ra. The contact load is a linear load obtained by dividing the spring load by

the cam width. As shown in Table 7, excellent anti-burn properties were obtained compared to the cast iron cam by using the camshaft assembly of this invention.

Table 7

Linear Burn Load of Test Piece

No.	Material	Linear burn load (kg /mm)
1	alumina	28
2	zirconia*1	16
3	silicon nitride	47
4	silicon carbide whisker-silicon nitride*2	42
5	silicon carbide particle-silicon nitride*3	45
6	cast iron*1	12

Notes

1) *1: Comparative examples
2) *2: Silicon nitride reinforced with a dispersion of silicon carbide whiskers
3) *3: Silicon nitride reinforced with a dispersion of silicon carbide nanoparticles

Example 5

A super high speed test was performed on a camshaft assembly using each material shown in Table 1 and Table 8. Of the silicon nitride sintered bodies in Table 8, No. 3-1 is the same material as No. 3 in Table 1. No. 3-2 and No. 3-3 have an even smaller grain size, and therefore high strength. In the super high speed test, the same motoring device as in Examples 2 - 4 was used, and the revolving speed was increased from 3000 rpm in steps of 500 rpm. Each speed was maintained for 120 seconds. Only the cam piece of the camshaft assembly was constructed of a ceramic material, and the surface roughness Ra of the sliding surfaces in contact was 0.05 μm. As shown in Table 9, abnormal vibration occurred and burning was observed at an engine speed of 6500 rpm in the case of the conventional cast iron camshaft assembly. Whereas a materials having a 3-point bending strength of at least 120 kg /mm^2 based on JIS R1601 showed a great improvement in the number of revolutions at which breakage occurred due to surging and in particular, a camshaft assembly provided with a cam piece having a bending strength of 150 kg /mm^2 was not broken up to 9500 rpm.

Table 8

Test Piece			
No.	Material	grain size	3-point bending strength
3-1	silicon nitride 1	< 10 μm	100 kg /mm^2
3-2	silicon nitride 2	< 5 μm	120 kg /mm^2
3-3	silicon nitride 3	< 3 μm	150 kg /mm^2

Table 9

Number of Revolutions at Occurrence of Breakage

No.	Material	Number of revolutions at occurrence of breakage (rpm)
1	alumina	7500
2	zirconia*1	6500
3-1	silicon nitride 1	8000
3-2	silicon nitride 2	8500
3-3	silicon nitride 3	9500
4	silicon carbide whisker-silicon nitride*2	9000
5	silicon carbide particle-silicon nitride*3	9000
6	cast iron*1	6500

Notes

1) *1: Comparative examples
2) *2: Silicon nitride reinforced with a dispersion of silicon carbide whiskers
3) *3: Silicon nitride reinforced with a dispersion of silicon carbide nanoparticles

As described hereintofore, this invention provides a camshaft assembly which permits a large reduction of power loss and improvement of the antiwear properties of a moving valve train of an internal combustion engine used in an automobile or the like, thereby giving better engine fuel cost-performance, output and endurance, and improved reliability in the dangerous engine speed region.

Claims

1. A camshaft assembly comprising a metal camshaft, a cam piece constructed of a ceramic material, a cam follower and a cam journal piece, the surface roughness Ra of said cam piece being not greater than 0.1 μm, and the Vickers hardness of said cam piece being not less than 1000 kg /mm^2.

2. A camshaft assembly as defined in claim 1 wherein the modulus of longitudinal elasticity of the ceramic material constituting said cam piece is not less than 25000 kg /mm^2, and the Vickers hardness of the same is not less than 1000 kg /mm^2.

3. A camshaft assembly as defined in claim 1 or 2 wherein said cam journal piece is constructed of a ceramic material.

4. A camshaft assembly as defined in any one of claims 1 to 3 wherein the contact pressure between the surfaces of said cam piece and said cam follower which are in contact is not less than 20 kg /mm in terms of linear load.

5. A camshaft assembly as defined in any of claims 1 to 4 wherein the surface roughness Ra of the sliding surfaces of said cam piece and said cam follower which are in contact does not exceed 0.1 μm.

6. A camshaft assembly as defined in any of claims 1 to 5 wherein said ceramic material used in said camshaft assembly has a 3-point bending strength of not less than 120 kg /mm^2 measured by the 3-point bending test according to JIS R1601.

7. A camshaft assembly as defined in any of claims 1 to 6 wherein said ceramic material used in the camshaft assembly has a 3-point bending strength of not less than 150 kg /mm^2.

8. A camshaft assembly as defined in any of claims 1 to 7 wherein said ceramic material has a silicon nitride matrix.

Patentansprüche

1. Nockenwellenanordnung mit einer Nockenwelle aus Metall, einem aus einem keramischen Werkstoff hergestellten Nockenstück, einem Nockenstößel und einem Nockenlagerstück, wobei die Oberflächenrauheit Ra des Nockenstücks nicht größer ist als 0,1 μm und die Vickershärte des Nockenstücks nicht unter 1000 kg/mm^2 liegt.

2. Nockenwellenanordnung nach Anspruch 1, wobei das Längselastizitätsmodul des das Nockenstück bildenden keramischen Werkstoffs nicht unter 25000 kg/mm^2 und seine Vickershärte nicht unter 1000 kg/mm^2 liegt.

3. Nockenwellenanordnung nach Anspruch 1 oder 2, wobei das Nockenlagerstück aus einem keramischen Werkstoff hergestellt ist.

4. Nockenwellenanordnung nach einem der Ansprüche 1 bis 3, wobei der Kontaktdruck zwischen den Flächen des Nockenstücks und des Nockenstößels, die in Kontakt stehen, bei linearen Lastbedingungen nicht unter 20 kg/mm liegt.

5. Nockenwellenanordnung nach einem der Ansprüche 1 bis 4, wobei die Oberflächenrauheit Ra der Gleitflächen des Nockenstücks und des Nockenstößels, die in Kontakt stehen, nicht größer ist als 0,1 μm.

6. Nockenwellenanordnung nach einem der Ansprüche 1 bis 5, wobei der in der Nockenwellenanordnung verwendete keramische Werkstoff eine Dreipunkt-Biegefestigkeit von nicht unter 120 kg/mm^2, gemessen mit der Dreipunkt-Biegeprüfung gemäß JIS R1601, aufweist.

7. Nockenwellenanordnung nach einem der Ansprüche 1 bis 6, wobei der in der Nockenwellenanordnung verwendete keramische Werkstoff eine Dreipunkt-Biegefestigkeit nicht unter 150 kg/mm^2 aufweist.

8. Nockenwellenanordnung nach einem der Ansprüche 1 bis 7, wobei der keramische Werkstoff eine Siliciumnitrid-Matrix aufweist.

Revendications

1. Un ensemble d'arbre à cames comprenant un arbre à cames métallique, un système de came(s) fabriquée(s) à partir d'un matériau céramique, un système de contre-came(s) et un système de collet de palier de cames, la rugosité de surface Ra dudit jeu de cames ne dépassant pas 0,1 μm et la dureté Vickers dudit jeu de cames n'étant pas inférieure à 1000 kg/mm^2.

2. Un ensemble d'arbre à cames tel que défini dans la revendication 1 dans lequel le module d'élasticité longitudinale du matériau céramique qui constitue ladite came n'est pas inférieur à 25000 kg/mm^2, et dans lequel la dureté Vickers du même matériau n'est pas inférieure à 1000 kg/mm^2.

3. Un ensemble d'arbre à cames tel que défini dans la revendication 1 ou 2, dans lequel ledit collet de palier de cames est fabriqué dans un matériau céramique.

4. Un ensemble d'arbre à cames tel que défini dans l'une quelconque des revendications 1 à 3, dans lequel la pression de contact qui s'exerce entre les surfaces de ladite came et ladite contre-came qui sont en contact l'une avec l'autre, n'est pas inférieure à 20 kg/mm en termes de charge linéaire.

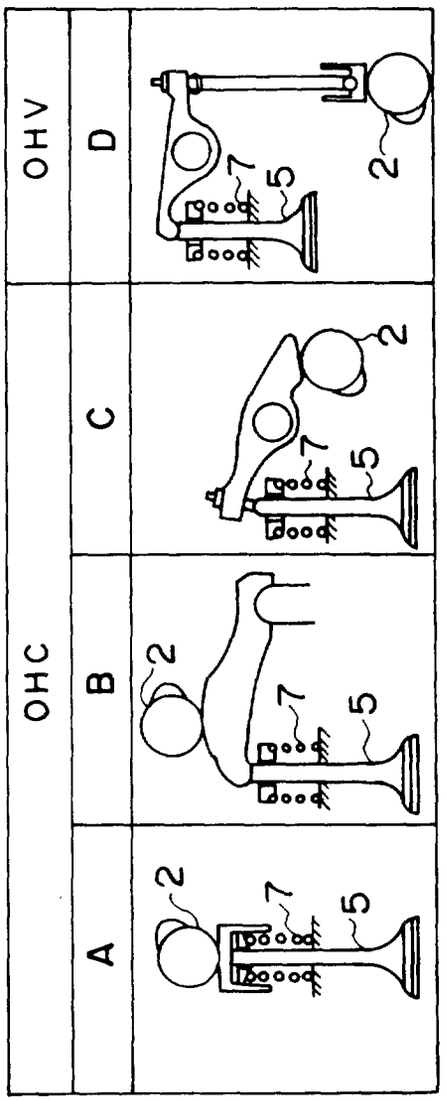
5. Un ensemble d'arbre à cames tel que défini dans l'une quelconque des revendications 1 à 4, dans lequel la rugosité de surface Ra des surfaces de contact mécanique de ladite came et de ladite contre-came qui sont en contact l'une avec l'autre, ne dépasse pas 0,1 μm.

6. Un ensemble d'arbre à cames tel que défini dans l'une quelconque des revendications 1 à 5, dans lequel ledit matériau céramique utilisé dans ledit ensemble d'arbre à cames possède une résistance à la flexion 3-point qui n'est pas inférieur à 120 kg/mm^2 mesurés par le test de résistance à la flexion 3-point selon JIS R1601.

7. Un ensemble d'arbre à cames tel que défini dans l'une quelconque des revendications 1 à 6, dans lequel ledit matériau céramique utilisé dans l'ensemble d'arbre à cames présente une résistance à la flexion 3-point qui n'est pas inférieure à 150 kg/mm^2.

8. Un ensemble d'arbre à cames tel que défini dans l'une quelconque des revendications 1 à 7, dans lequel ledit matériau céramique possède une matrice en nitrure de silicium.

FIG. 1



A : DIRECT DRIVE SYSTEM
B : SWING ARM SYSTEM
C : ROCKER ARM SYSTEM
D : PROJECTING ROD SYSTEM

FIG. 2

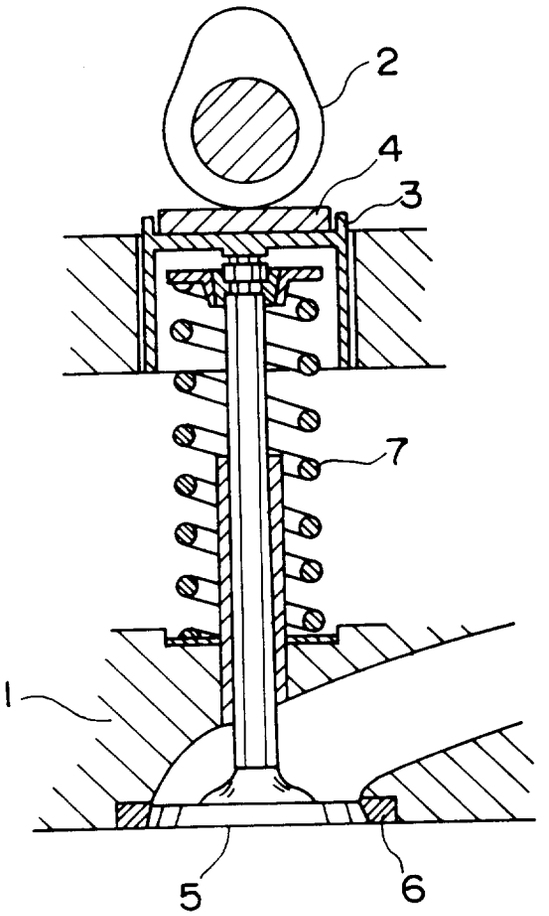


FIG. 3

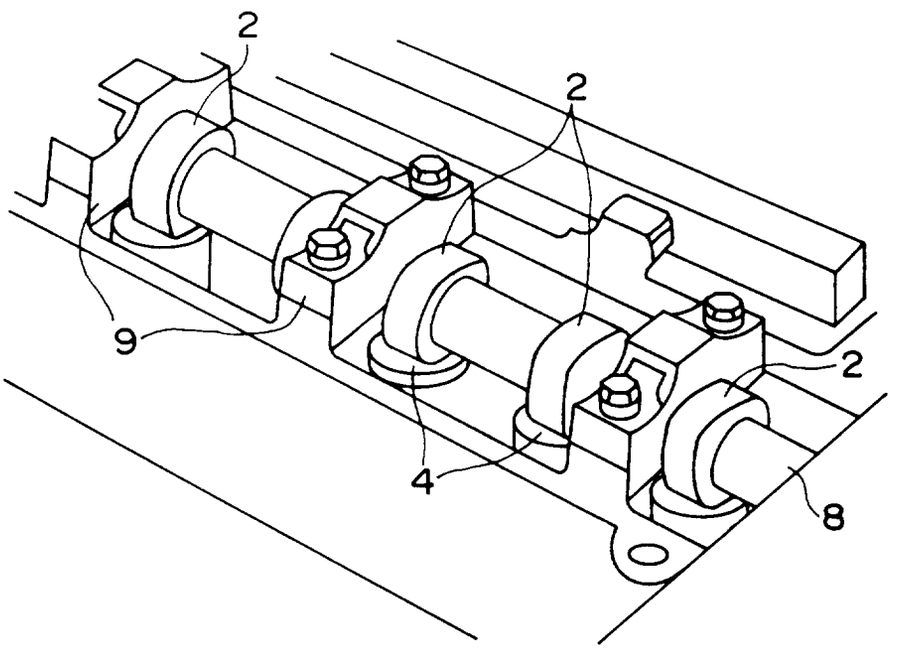


FIG. 4

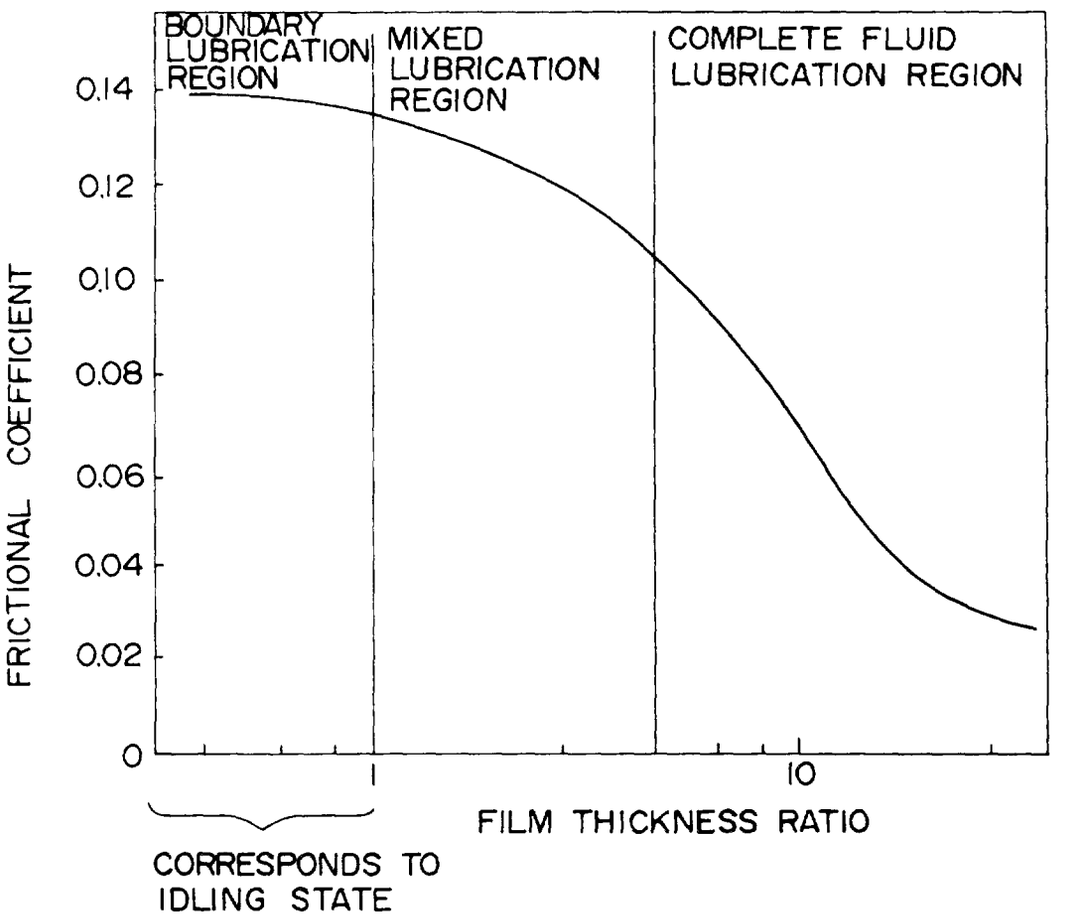

BOUNDARY LUBRICATION REGION
MIXED LUBRICATION REGION
COMPLETE FLUID LUBRICATION REGION
FRICTIONAL COEFFICIENT
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0
1
10
FILM THICKNESS RATIO
CORRESPONDS TO IDLING STATE

FIG. 5

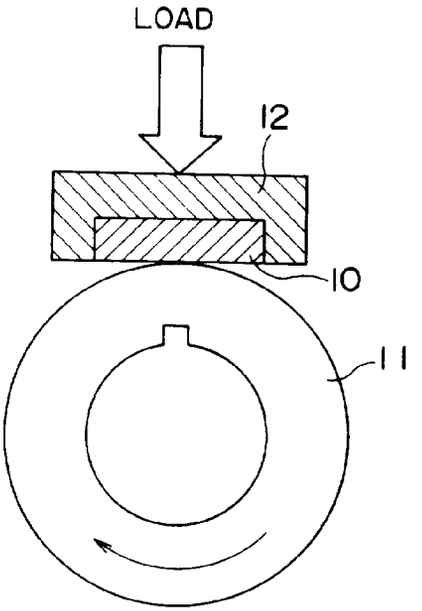

LOAD
12
10
11

FIG. 6

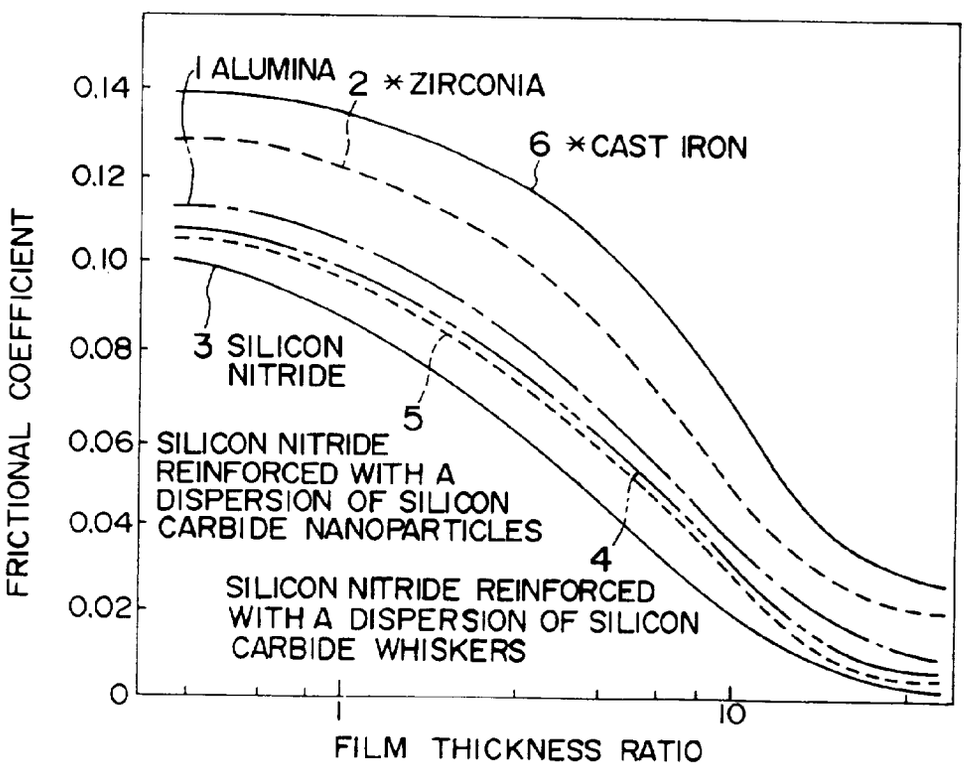

1 ALUMINA
2 *ZIRCONIA
6 *CAST IRON
3 SILICON NITRIDE
5
SILICON NITRIDE REINFORCED WITH A DISPERSION OF SILICON CARBIDE NANOPARTICLES
4
SILICON NITRIDE REINFORCED WITH A DISPERSION OF SILICON CARBIDE WHISKERS
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0
1
10
FRICTIONAL COEFFICIENT
FILM THICKNESS RATIO

FIG. 7

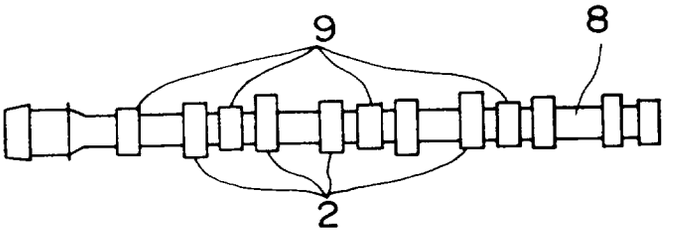


FIG. 8

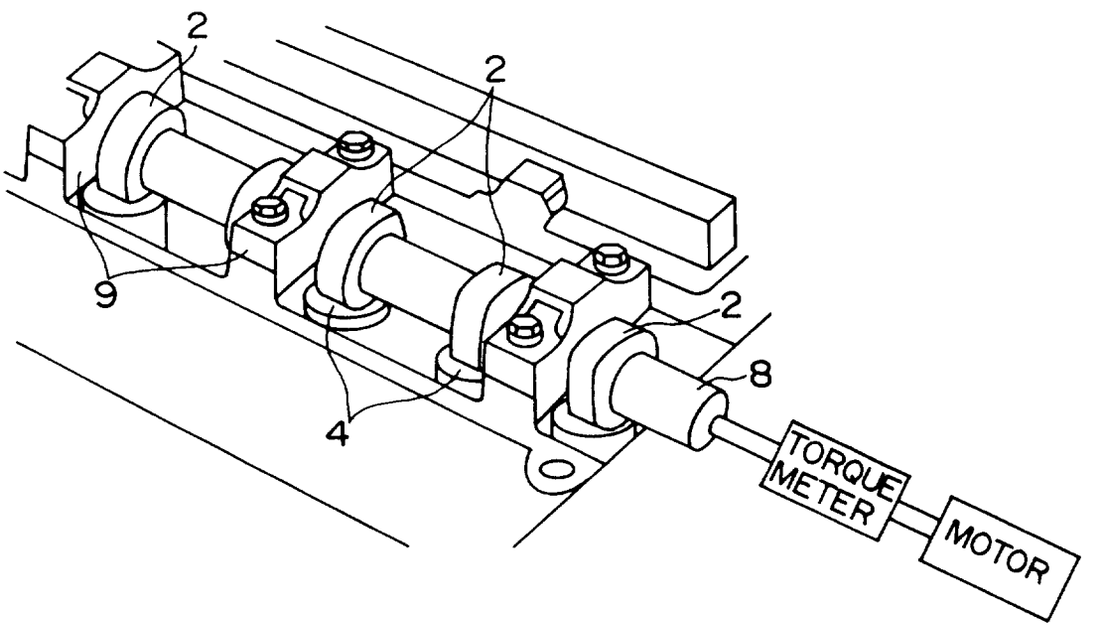
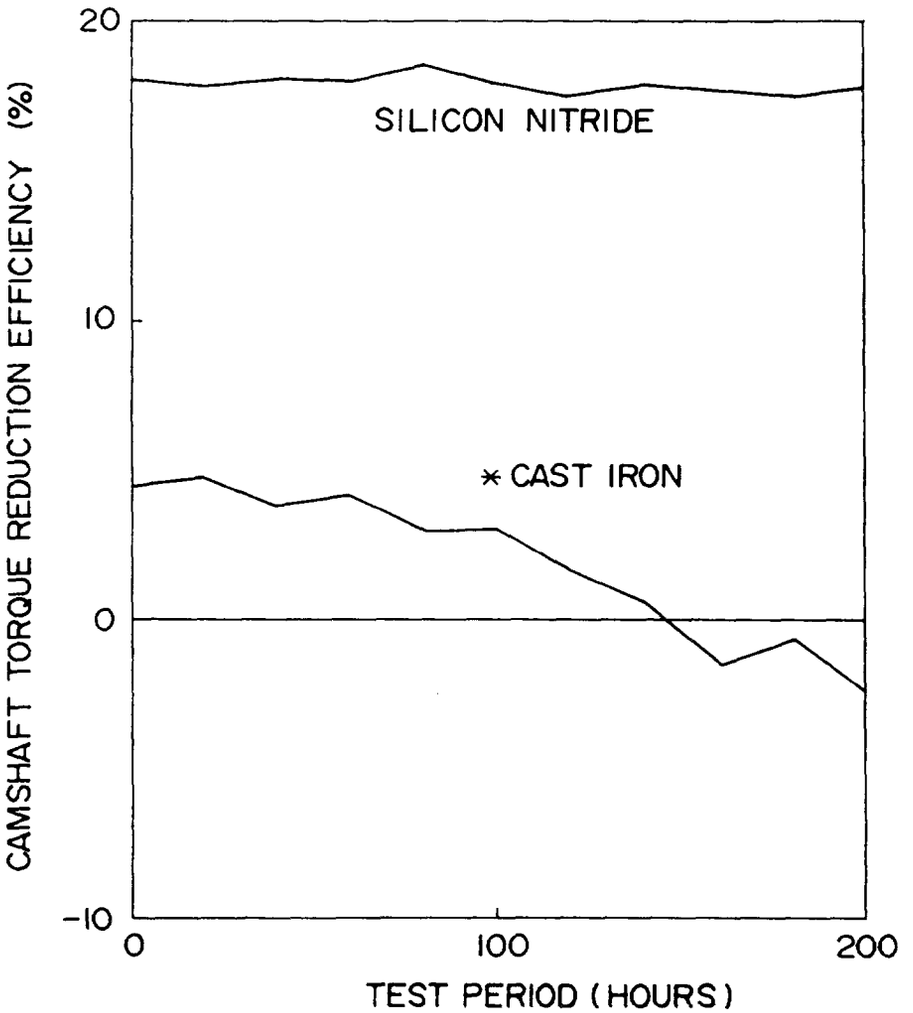


FIG. 9


20
10
0
-10
0
100
200
SILICON NITRIDE
* CAST IRON
CAMSHAFT TORQUE REDUCTION EFFICIENCY (%)
TEST PERIOD (HOURS)