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Proceeding Paper

Feasibility Study on Evaluation Method for Plateau Surfaces by Conic Curve Fitting Using Information of Conjugate Diameter †

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Abstract: Plateau surfaces have excellent sliding properties because only the high peaks of surface asperity are smoothed. Therefore, they form the sliding surfaces for automobile engines and machine tools, contributing to their high performance and low environmental impact. As the development and production of these machines require the evaluation of their plateau surface components, methods for plateau surface evaluation have been proposed by the International Organization for Standardization (ISO) and in previous research. These evaluation methods include a processing procedure for fitting a hyperbola to the material probability curve (MPC) of a plateau surface. However, the ISO standard does not clearly state the rationale for restricting the fitting curve to a hyperbola. As shown in a previous study, another curve that can fit the shape of the MPC of a plateau surface is expected to be a parabola in addition to a hyperbola. Parabolas and hyperbolas are curves known as conic sections. In this research, we examine the validity of hyperbolic curve fitting and explore the fitting of a conic curve by utilizing information on conjugate diameters. Approximations using a curve better suited to the shape of the MPCs of the plateau surface can anticipate to the realization of higher-quality evaluations of the surface. Through this research, we aim to contribute to the development of industry as well as improve the performance and mitigate the environmental impact of automobile engines and machine tools.

Keywords: plateau surface; surface texture; surface roughness; material probability curve; material ratio curve; ISO 21920-2

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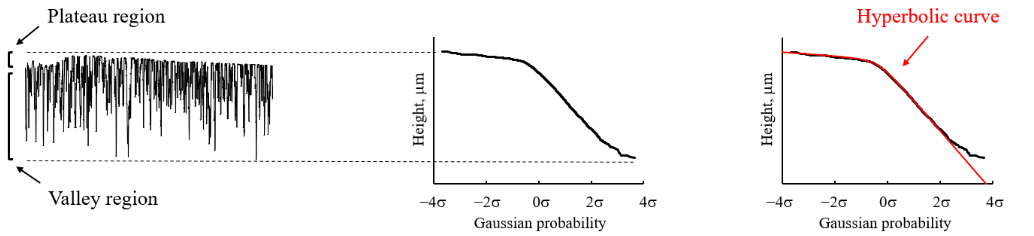
1. Introduction

Machines must exhibit high performance, satisfactory durability, and be under low environmental loads to achieve global goals, such as sustainable development goals (SDGs) and carbon neutrality. The surface shown in Figure 1a is called a surface with stratified functional properties or a plateau structure surface (a plateau surface). The plateau surface consists of smooth and rough regions because only high peaks of surface asperity are smoothed. The smooth-plateau region functions as the base for the formation of the lubricant film and load bearing, whereas the rough-valley region functions as a lubricant basin. Therefore, the plateau surface exhibits excellent sliding properties. Plateau surfaces with these functions are manufactured as sliding surfaces for automobile engines and machine tools, contributing to their high performance, good durability, and low environmental impact. The development and production of machines with plateau surfaces require the evaluation of plateau surface components. Plateau surfaces are difficult to evaluate using the widely used roughness parameters *Ra* or *Rz* [1] because the two regions must be evaluated separately. Methods for evaluating the two regions separately have been proposed by the International Organization for Standardization (ISO) [2,3] and in previous studies [4–8].

These methods can evaluate each region separately using a material probability curve (MPC), as shown in Figure 1b. These methods include a processing procedure for fitting a hyperbola to the MPC of a plateau surface, as shown in Figure 1c. However, the ISO standard does not clearly state the rationale for limiting curve fitting to a hyperbola. In addition to a hyperbola, another curve that is thought to be able to fit the MPC shape of a plateau surface is a parabola. Parabolas and hyperbolas are curves that are known as conic sections. In this study, we examine the validity of hyperbolic curve fitting and explore the fitting of a conic curve using information on conjugate diameter. Approximations using a curve that is better suited to the MPC shape of a plateau surface can improve the evaluation quality of the surface. Through this study, we aim to contribute to the development of industry and improve the performance and environmental impact reduction of automobile engines and machine tools.



(**a**) Primary profile of the plateau surface. (**b**) Material probability curve of the plateau surface. (**c**) Hyperbolic curve fitting.

Figure 1. Primary profile and material probability curve of the plateau surface.

2. Evaluation Method for Plateau Surface

The evaluation method for a plateau surface is defined in the ISO standards [2,3], and the roughness of the plateau and valley regions is calculated according to the following procedure:

I. The first hyperbolic fitting to the MPC is performed.
II. The point of intersection between the bisector of the asymptote of the fitted hyperbola and MPC is calculated. This intersection point is set as the temporary transition point from the plateau region to the valley region.
III. The second derivative of the MPC is calculated from the transition point to the plateau and valley regions. The calculated second derivative is then divided by the standard deviation of the second derivative. The position where the absolute value of these values exceeds six is defined as the upper-plateau limit (UPL) or lower-valley limit (LVL).
IV. The vertical axis of the MPC is normalized so that the region from the UPL to LVL becomes a square.
V. A second hyperbolic fitting is performed on the normalized MPC. The asymptotes of the fitted hyperbola are then calculated.
VI. The asymptotes of the hyperbola are bisected three times. The lower-plateau limit (LPL) is determined to be the intersection of the third bisector on the plateau region side and the MPC. The upper-valley limit (UVL) is determined to be the intersection of the third bisector on the valley region side and the MPC.
VII. The range of the plateau region is determined as the data from the UPL to the LPL, and the range of the valley region is determined to be the data from the UVL to the LVL. A linear regression is performed for each range. The roughness parameters, *Rpq* of the plateau region, *Rvq* of the valley region, and the material length ratio *Rmq*, which is an index of the border between the plateau and valley regions, are calculated from the slopes and intersection of the two regression lines [8].

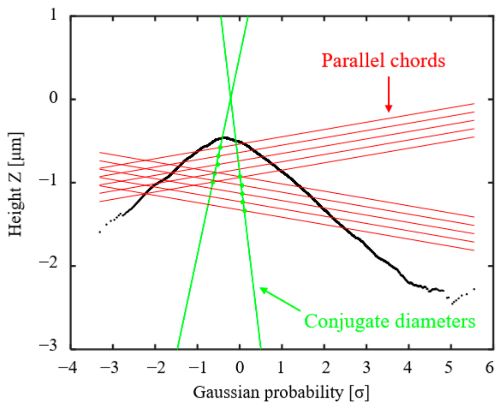
In the method for evaluating a plateau surface defined by the ISO standards [2,3], hyperbolic fitting is required in Steps I and V of these processing procedures. However, the ISO standard [2,3] does not clearly state the rationale for limiting the fitting curve to a hyperbola. Another curve that fit the MPC shape of the plateau surface is expected to be a parabola, in addition to a hyperbola. Parabolas and hyperbolas are conical sections. To realize higher-quality evaluations of a surface, we examined the validity of hyperbolic curve fitting and investigated the fitting of a conical curve using conjugate diameter information.

3. Conic Curve Fitting Using Conjugate Diameter Information

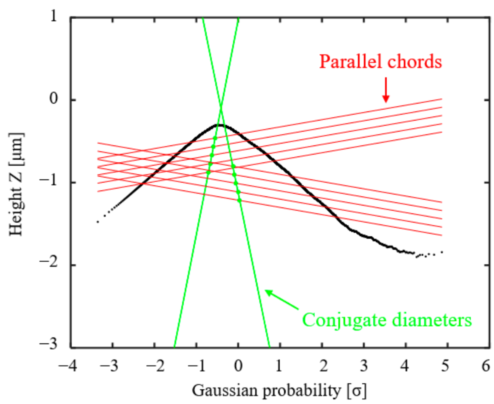
In this study, the conjugate diameter of the MPC on the plateau surface is calculated, and the fitting of a conic curve to the MPC on the plateau surface is performed using this conjugate diameter information. The conjugate diameter is the locus of the centers of the parallel chords. For the hyperbola, the conjugate diameters intersect at the center of the curve. In contrast, for the parabola, the conjugate diameters align parallel to the axis of the curve. In this study, using such conjugate diameter information, conic curve fitting is performed on the MPC of the plateau surface. Furthermore, the calculation of the roughness parameters *Rpq*, *Rvq*, and *Rmq* is attempted.

4. Experiments and Results

The experimental data of this study are G1 with *Ns* = 8000 and G5 with *Ns* = 9000 from previous studies [8,9]. *Ns* is the number of slides by the experimental equipment in [9]. Figure 2a,b show the results of calculating the two conjugate diameters for each MPC of the two experimental datasets. The MPC is temporarily rotated downward to help confirm the appearance of the conjugate diameter. Conic curve fitting was then performed using the conjugate diameter information. The hyperbola Z_H fitted to the MPC is calculated using the coordinate information of the intersection points of the conjugate diameters based on Equations (1)–(4) in a previous study [8]. Figure 3a,b show the calculated hyperbola, Z_H. As shown in Figure 3a,b, the calculated hyperbolas satisfactorily fit the MPCs of the plateau surfaces of G1 and G5 [8,9]. Finally, the roughness parameters *Rpq*, *Rvq*, and *Rmq* are calculated. The roughness parameters are calculated by conforming to the evaluation procedure stated in the ISO standard [2,3]. Among the evaluation procedures, hyperbolic fitting is performed using conjugate diameter information. Table 1 lists the roughness parameters calculated based on the evaluation procedure for a plateau surface [2,3]. As listed in Table 1, we successfully calculated the roughness parameters *Rpq*, *Rvq*, and *Rmq*. In the future, we plan to apply the proposed method to the MPCs of plateau surfaces with various shapes, such as plateau surfaces in initial wear states [10–12], and to verify the validity of the proposed method.

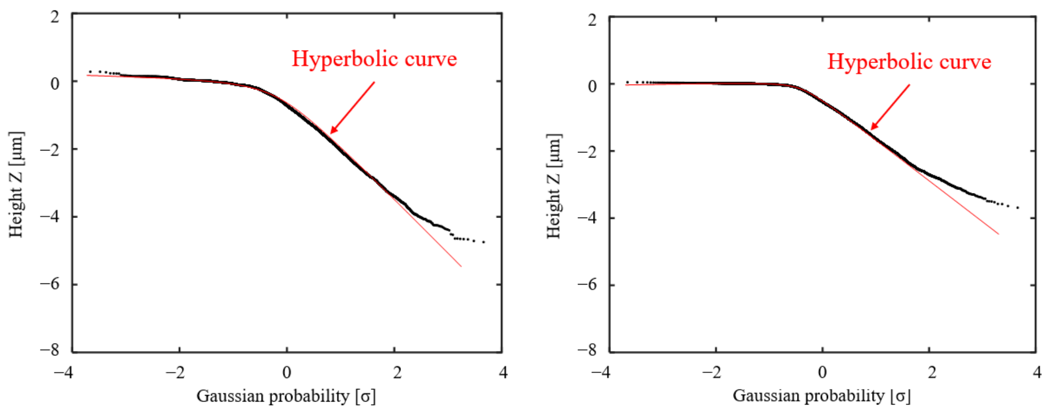


(**a**) G1 *Ns* = 8000



(**b**) G5 *Ns* = 9000

Figure 2. Calculation results regarding the conjugate diameters in the MPC of the plateau surface.



(**a**) G1 *Ns* = 8000 (**b**) G5 *Ns* = 9000

Figure 3. Experimental results of hyperbolic fitting.

Table 1. Calculation results regarding roughness parameters *Rpq*, *Rvq*, and *Rmq*.

Specimen No.	*Rpq*, μm	*Rvq*, μm	*Rmq*, %
G1 *Ns* = 8000	0.14	1.3	34
G5 *Ns* = 9000	0.03	1.1	32

5. Conclusions

The main conclusions and future avenues of this research are summarized as follows.

I. In this study, a method for conic curve fitting was developed using conjugate diameter information for the material probability curve (MPC) of a plateau surface. The results showed that the calculated curves fit the MPCs for G1 and G5.

II. Roughness parameters *Rpq*, *Rvq*, and *Rmq* were successfully calculated using the method developed in this study. We propose this newly developed fitting method that uses conjugate diameter information.

III. In the future, we plan to apply the proposed method to MPCs of plateau surfaces with various shapes and verify the validity of the proposed method.

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