

# Study of Evaluation Method for Knee-grip Feeling of Motorcycles

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## ABSTRACT

Simulation technology is demanded that enables quantitative and unified evaluation of the knee-grip feeling of motorcycles in a short time. This study used a computer mannequin, which can simulate various rider physiques, and ergonomic techniques to derive the appropriate relative positions of the foot peg and knee contact area that enable riders to exert sufficient gripping force. In addition, the knee-grip status was reproduced using simulations, and the relationship with the subjective rating was investigated. This enabled establishing of evaluation parameters that express the feeling of discomfort during knee gripping and threshold values, and deriving of a predictive formula. As a result, it became computationally possible to estimate the feeling of thigh discomfort with an accuracy of 93%.

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## 1. Introduction

When riding motorcycles, riders clasp the motorcycle body between their thighs and grip it with their knees. When this knee-grip is insufficient, the correct riding posture is sometimes lost when running over rough roads or accelerating and decelerating rapidly, making it challenging to stabilize the motorcycle body. When the shape of the contact area does not match that of the thighs during knee gripping, riders may feel some discomfort such as pain or localized pressure that prevents them from exerting sufficient gripping force. Conventionally, the knee-grip feeling was evaluated by having expert riders straddle a mock-up equivalent of the actual vehicle and confirm by subjective rating whether the shape enabled sufficient knee gripping without a feeling of discomfort in the thighs. However, there were issues such as mock-ups are easily damaged, so sufficient force could not be applied, making it a challenge to understand the degree of discomfort; or the seat and other mock-up parts are not deformed, making it a challenge to accurately understand the areas that the legs contact. In addition, even when using an actual vehicle, the areas that the legs contact depend on the leg length of the test subject, so there was also the issue of individual differences in the ratings. For these reasons, the construction of simulation technology is desired that enables quantitative and unified evaluation of the knee-grip feeling.

Regarding the subject of contact between the human body and machines, studies are being conducted on grasp and seated comfort. Koyano et al. were able to

computationally evaluate the fit feeling of the motorcycle seat by reproducing the body pressure distribution when sitting on the seat through nonlinear finite element method analysis<sup>(1)</sup>. It is expected that knee grip can also be evaluated using similar techniques. However, nonlinear finite element method analysis requires much time to create special mesh models for analysis and to perform the calculations. The knee-grip surface shape has a strong influence on the motorcycle body styling and the internal structure such as the gasoline tank, so it needs to be decided in the early stage of development. Therefore, it is challenging to apply nonlinear finite element method analysis under the present situation.

When dealing with an elastic body such as a seat, deformation due to the load from the human body should also be taken into account. On the other hand, the areas contacted during knee gripping are mainly the gasoline tank and the side covers, which are comparatively resistant to deformation. The authors investigated whether the knee-grip surface shape can be evaluated in a short period of time by assuming these parts to be rigid bodies and using a standardized human body model.

This study uses a computer mannequin, which can simulate various rider physiques, and ergonomic techniques<sup>(2), (3)</sup> to obtain the leg posture that enables riders to exert sufficient gripping force, and to derive the appropriate relative positions of the foot peg and knee contact area. In addition, a method is proposed to evaluate mock-up surface shape data in a short time by using the numerical evaluation parameters and the threshold values that express the feeling of discomfort during knee gripping.

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## 2. Rider Model

The feeling of discomfort during knee gripping refers to the difficulty of exerting force and the feeling of localized pressure on the thighs. Motorcycle body characteristics that produce a feeling of discomfort were investigated based on conventional riding tests by expert riders, and it was found that these characteristics can be broadly grouped into the following two factors.

- (1) Sufficient gripping force: Relative positions of foot peg and knee contact area
- (2) Feeling of discomfort produced by the contact surface:  
Thigh contact surface shape

This study constructed a rider model that enables investigation of these two factors.

### 2.1. Creation of a Rider Model

A knee-grip simulation model was constructed using a model that simulates a mock-up surface and a rider in order to derive the locations that the rider's legs contact and the leg posture using a computer. The surface data of the locations that the legs contact was imported to CAD, and a rider model was created using the computer mannequin "RAMSIS" made by Human Solutions GmbH.

The RAMSIS software does not include information such as the internal tissues of the human body, but the physique can be changed and natural poses can be created that contact the given constraint points without exceeding the range of motion of each joint. In addition, the permanently exorable maximum isometric force (the force that can be exerted without changing the muscle length) corresponding to each posture can be output. RAMSIS used the body dimension data for various countries<sup>(4), (5)</sup> as the input to express physiques corresponding to the target users.

To express the riding posture, RAMSIS constrained the hands to the handle grips, the soles of the shoes to the foot pegs, and the center point between the ischial tubercles to the hip point (HP) in consideration of seat deformation. In addition, the hip joints were rotated inward so that the knees

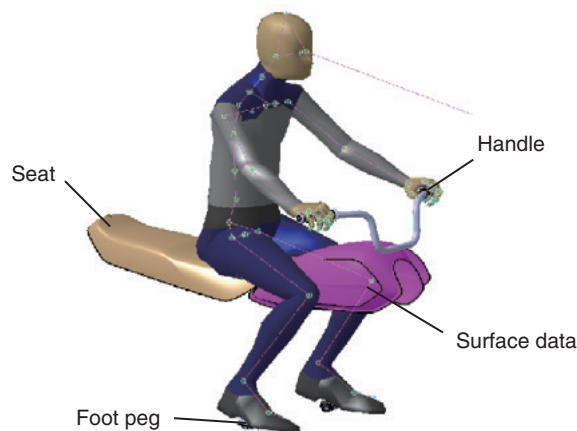


Fig. 1 Rider model

contacted the mock-up surface data. This was defined as the rider model (Fig. 1).

## 3. Relative Positions of Foot Peg and Knee Contact Area

### 3.1. Hip Joint Angles and Gripping Force

The ability to exert sufficient gripping force during knee gripping depends on the leg posture. Figure 2 shows the definitions of the human body joint angles. First, the gripping force of the legs for different hip joint abduction angles and internal rotation angles was obtained using the RAMSIS function that outputs the exorable maximum isometric force. The gripping force is the sum of the Y-axis forces that can be exerted by the knees and the ankles. Figure 3 shows the results.

Next, a simplified model was used to derive the

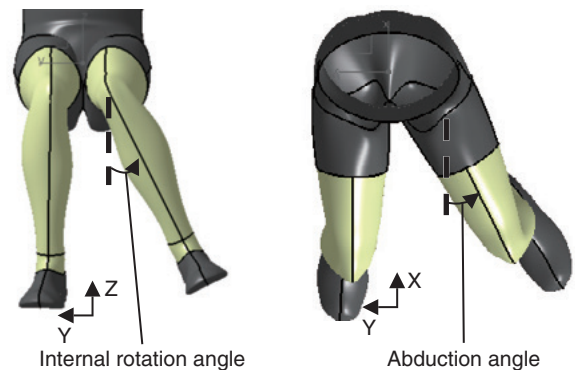


Fig. 2 Definition of angles around hip joint

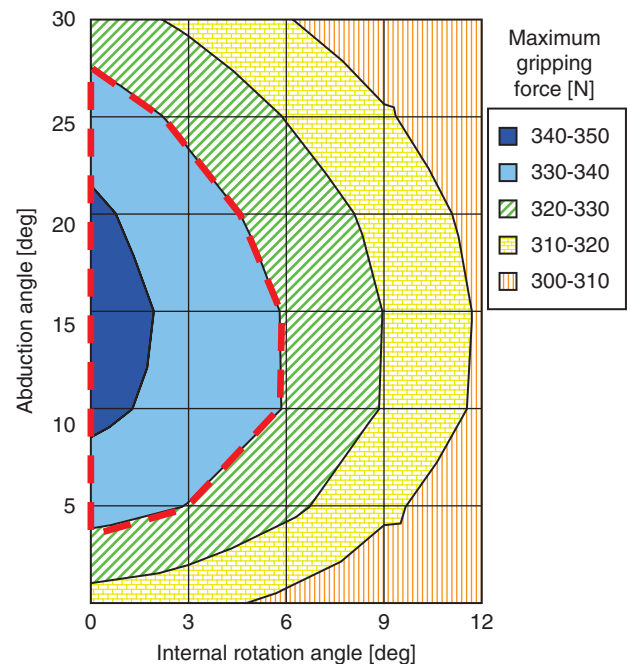


Fig. 3 Maximum gripping force in relation to hip joint angles

relational expression between acceleration and the gripping force  $T$  of a single leg required to support the upper body using only the legs. Here,  $M$  is the distributed mass of the upper body,  $\alpha$  is the acceleration produced by braking or other factors,  $g$  is the acceleration of gravity,  $\mu_1$  is the coefficient of static friction between the clothing and the knee-grip surface, and  $\mu_2$  is the coefficient of static friction between the clothing and the seat. As shown by Eq. (1), it is hypothesized that to prevent the body from shifting forward or back due to deceleration or acceleration, the total force of the friction force  $2T\mu_1$  generated between the knee-grip surfaces and the knees and the friction force  $Mg\mu_2$  generated between the seat and the buttocks should be equal to or greater than the force  $M\alpha$  applied to the upper body.

$$M\alpha \leq 2T\mu_1 + Mg\mu_2 \quad (1)$$

Converting the above equation yields Eq. (2).

$$T \geq M(\alpha - g\mu_2) / 2\mu_1 \quad (2)$$

Using the hypothetical case of a rider with a typical physique performing sudden braking,  $M = 42$  kg (JM50%tile) and  $\alpha = 5.6$  m/s<sup>2</sup> (corresponding to sudden braking as specified by driving schools: stopping in 11 m from a velocity of 40 km/h) were substituted to Eq. (2). In addition, the coefficient of static friction of cloth depends on the fiber direction, water content, temperature, and other factors. Therefore, 0.22 was substituted to  $\mu_1$  and  $\mu_2$  as reference values based on cases of measuring the coefficient of static friction of cotton<sup>(6)</sup>. In case of the aforementioned conditions, Eq. (2) indicates that a gripping force  $T$  of 330 N or more is required. Thus, it is thought that the leg posture should be set within the range indicated by the red broken line in Fig. 3.

### 3.2. Relationship between Foot Peg Width and Knee Contact Area Width

The leg posture when riding a motorcycle is determined by the relative positions of the center point of the foot peg and the knee contact area on the knee-grip surface. Therefore, a rider model (JM50%tile) that simulates a typical motorcycle riding posture was used, and the internal rotation angle and abduction angle of the hip joint were changed within the range in which gripping force of 330 N or more can be exerted. The relative positions of the shoe sole center point and the tibia point of the rider model at this time were investigated. The center of the shoe sole contacts the center of the foot peg and the tibia point contacts the knee-grip surface, so these results are shown in Fig. 4 as the relative positions of the foot peg center width and the knee contact area width (width: distance from vehicle's center plane). Sufficient gripping force can be exerted within the red-colored range shown in Fig. 4, so this was established as the recommended area. However, in consideration of the engine and frame size, it is not realistic to set a foot peg center width of 200 mm or less for a saddle-type motorcycle. Therefore, the range of 200 mm or less was excluded from the recommended area. The relative

positions of 20 existing motorcycle models judged to enable sufficient knee gripping were investigated and single regression analysis was performed to confirm the validity of this range. In addition, the 95% prediction interval of the values predicted by regression was derived. Figure 5 shows the results, which confirmed that the recommended area is within the prediction interval. That is to say, the set recommended area is within the prediction error margin of the regression formula, indicating that the recommended area is not too large. In addition, approximately 95% of the measured models were within the recommended area. These results indicate that the range shown in Fig. 4 is valid, and it can be said that the relative positions of the foot peg and knee contact area should be set within this range to enable exertion of sufficient gripping force.

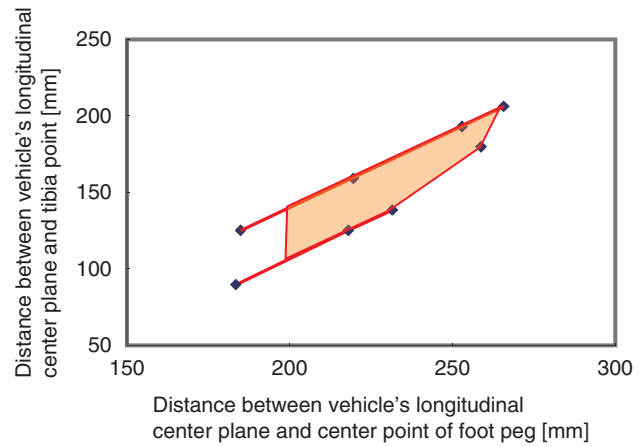


Fig. 4 Relative positions of foot peg and knee contact area that enable exertion of necessary force for gripping

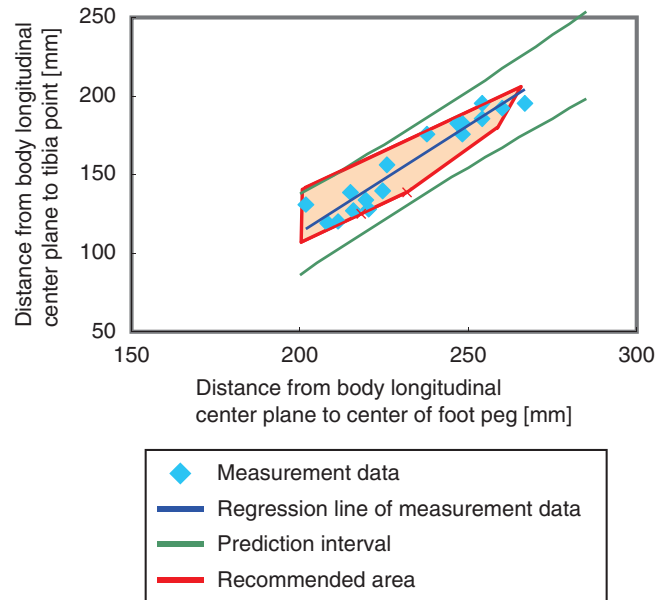


Fig. 5 Verification of appropriateness of recommended area

## 4. Evaluation of Thigh Contact Surface Shape

The relative positions of the thigh and knee-grip surface of the rider model were quantified through simulations, and the relationship between these values and the subjective ratings was investigated to evaluate the thigh contact surface shape.

### 4.1. Creation of State of Thigh Interference Model

The contact between the thigh and knee-grip surface of the rider model was checked on the computer and found to have a state of interference. The rider model is expressed using only surfaces, but the subcutaneous internal structure of the human body consists of tissues with different properties. The tissues near the skin surface in particular are soft tissues such as subcutaneous fat, so interference on the computer indicates yielding of the thigh area in the actual condition. It was thought that parameters expressing the feeling of discomfort that takes into account the degree of thigh yielding could be obtained by investigating this state of interference.

Therefore, the state of interference in the cross-section at the longitudinal center of the thigh was expressed numerically. As shown in Fig. 6, these parameters are the area over which the thigh interferes with the knee-grip surface (interference area), the ratio of the interference area to the thigh area (interference area ratio) and the depth of the interference area at the thigh center axis height (interference depth).

### 4.2. Investigation of Parameters Expressing a Feeling of Discomfort

#### 4.2.1. Test subjects

The test subjects were 23 healthy men and women (19 men, 4 women) with experience riding motorcycles. Table 1 shows the physical characteristics values (average values and standard deviations) of the test subjects.

#### 4.2.2. Experimental method

Five motorcycles with different knee-grip surface shapes were prepared (Table 2). The test subjects sat on the motorcycles in the stationary upright condition and rated the knee-grip feeling. Two seated positions were used: the position where the center point between the ischial tubercles matches the design HP (normal position), and the position seated as far forward as possible that produces the greatest

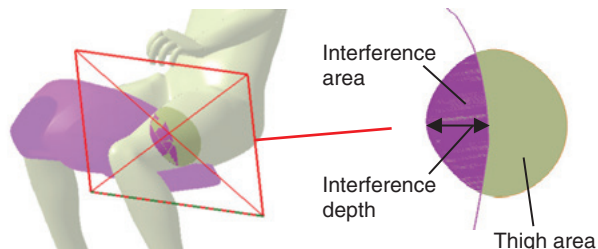


Fig. 6 State of interference of rider model

Table 1 Body sizes

|                                  | Male  |      | Female |      |
|----------------------------------|-------|------|--------|------|
|                                  | Ave.  | S.D. | Ave.   | S.D. |
| Height                           | 171.2 | 5.9  | 156.3  | 6.2  |
| Thigh length                     | 393.3 | 38.0 | 371.3  | 22.9 |
| Distance between tibia and groin | 351.1 | 26.3 | 322.5  | 35.9 |
| Lower leg length                 | 407.6 | 28.0 | 342.5  | 33.0 |

(mm)

Table 2 Specifications of test motorcycles

| Name | Category | Engine displacement [cm <sup>3</sup> ] | Wheelbase [mm] | Seat height [mm] | Mass [kg] |
|------|----------|----------------------------------------|----------------|------------------|-----------|
| A    | Sports   | 125                                    | 1355           | 818              | 127       |
| B    | Street   | 125                                    | 1318           | 730              | 123       |
| C    | Street   | 150                                    | 1311           | 771              | 127       |
| D    | Touring  | 800                                    | 1464           | 816              | 238       |
| E    | Naked    | 1000                                   | 1493           | 796              | 245       |

Table 3 Simulation results and subjective ratings

|                 |   | Interference area [mm <sup>2</sup> ] | Interference area ratio [%] | Interference depth [mm] | Subjective rating [Point] |
|-----------------|---|--------------------------------------|-----------------------------|-------------------------|---------------------------|
| Normal position | A | 2615                                 | 19.0                        | 35.3                    | <b>3.0</b>                |
|                 | B | 150                                  | 1.3                         | 4.5                     | 4.1                       |
|                 | C | 1628                                 | 12.4                        | 23.9                    | 3.6                       |
|                 | D | 282                                  | 2.5                         | 6.2                     | 4.3                       |
|                 | E | 184                                  | 1.6                         | 4.7                     | 4.8                       |
| Front position  | A | 3334                                 | 22.0                        | 39.9                    | 3.2                       |
|                 | B | 3036                                 | 21.0                        | 36.4                    | 3.9                       |
|                 | C | 8578                                 | 58.0                        | 63.3                    | <b>2.6</b>                |
|                 | D | 2568                                 | 17.8                        | 33.6                    | 3.9                       |
|                 | E | 2323                                 | 15.3                        | 28.3                    | 4.0                       |
| <b>R</b>        |   | <b>0.66</b>                          | <b>0.67</b>                 | <b>0.73</b>             | -                         |

\*R: Correlation coefficient with subjective rating

feeling of knee-grip discomfort as known from experience (front position).

- (1) The normal position and front position were subjectively rated, assigning one point for a strong feeling of discomfort in the thigh area or knee and five points for no discomfort whatsoever. In addition, surface data was prepared for motorcycles A through E, and the state of interference with the thigh of the rider model was investigated using the method described in Section 4.1 above.
- (2) The test subjects gradually rotated their hip joints outward (abduction) from the knee-grip conditions described above, stopping at the position where they felt that further abduction of the hip joint would result in insufficient knee grip. The length of the thigh area in the direction from the tibia point to the groin that did not contact the knee-grip surface at this time was defined as the minimum non-contacting length, and measured.

#### 4.2.3. Results

- (1) Table 3 shows the subjective rating and simulation results. Note that the simulation values noted here are

the values derived using the JM50%tile rider model that is approximately equal to the average of the test subjects. The average subjective rating values of the test subjects showed that motorcycle A received the lowest normal position rating of 3.0 points, and motorcycle C received the lowest front position rating of 2.6 points.

In addition, comparison of the correlation coefficient  $R$  between the simulation values and the subjective rating values shows that interference depth exhibits the highest  $R$ . Therefore, a graph was plotted showing the interference depth for motorcycles A through E. As shown in Fig. 7, the graph coordinates use the tibia point at the cross-section of the thigh center axis as the origin, the line connecting the tibia point and the groin as the X axis, and the axis perpendicular to that line as the Y axis. Figure 8 shows a graph of the interference depth. Reading the characteristics of motorcycles A and C, which received low ratings, from Fig. 8 shows that motorcycle C exhibited the largest interference depth value of all the motorcycles, and motorcycle A exhibited a pointed shape compared to the other motorcycles. To express these characteristics numerically, an index was defined as follows based on the results in Fig. 8. Table 4 shows the calculation results for motorcycles A through E.

Interference depth:  $F(x)$ , Maximum interference depth:  $F(a)$   
Degree of protrusion:  $\{F(a) - F(a + 30) + F(a) - F(a - 30)\} / 2$   
(Here,  $a$  is the value of  $x$  when  $F(x)$  is maximum)

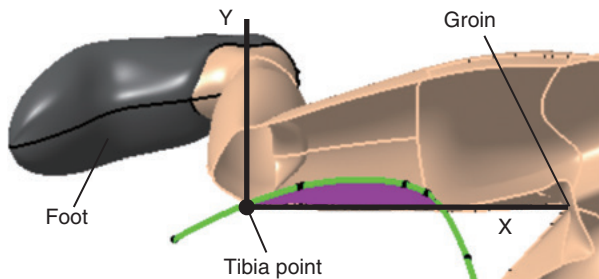


Fig. 7 Definition of axes

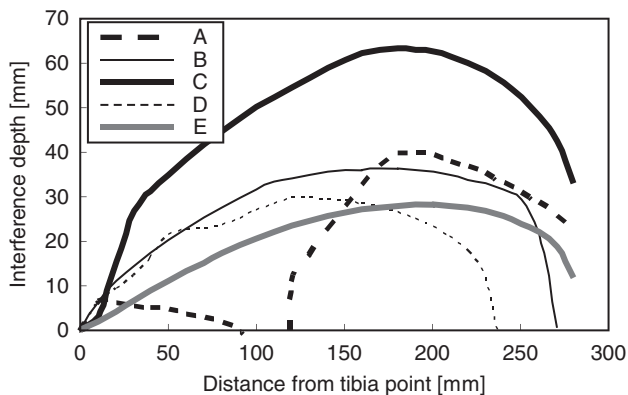


Fig. 8 Interference depth of motorcycles A-E (when seated at front position)

Table 4 Maximum interference depth and degree of protrusion (front position)

|                |   | $F(a)$ [mm] | Degree of protrusion |
|----------------|---|-------------|----------------------|
| Front position | A | 39.9        | 19.1                 |
|                | B | 36.4        | 0.9                  |
|                | C | 63.3        | 2.2                  |
|                | D | 29.9        | 2.2                  |
|                | E | 28.3        | 1.0                  |

- (2) The average minimum non-contacting length between the test subjects' thighs and the knee-grip surface was 80.3 mm, and the standard deviation was 5.6 mm. These results are thought to indicate that when the minimum non-contacting length is 80 mm or more from the tibia point, knee gripping becomes insufficient and the rider feels uneasy. Therefore, the minimum non-contacting length threshold value was set at 80 mm.

#### 4.3. Derivation of Interference Limit of Thigh

The thigh area of the rider model can interfere to any degree in simulations. However, bones and tendons are hardly transformed in the actual condition, and there are also cases where the tibia point cannot make contact depending on the shape of the knee-grip surface (Fig. 9). Therefore, the thigh yielding amount was measured and the interference depth limit value was derived in order to predict the location on the thigh where contact with the knee-grip surface begins in the actual condition.

##### 4.3.1. Test subjects

The test subjects were the same as those in Section 4.2.

##### 4.3.2. Experimental method

The thigh yielding amount was measured using an indentation hardness tester (TK-HS100) made by Tokushu Keisoku Co., Ltd.<sup>(7)</sup> The seated posture was used for measurement, and the seat height was adjusted so that the knee joint was bent by 90° in the flexion/extension direction. In addition, a rigid barrier was set along the outside of the thigh to prevent abduction of the hip joint when applying pressure. To help ensure a constant pressing direction, the measuring instrument height was variable as

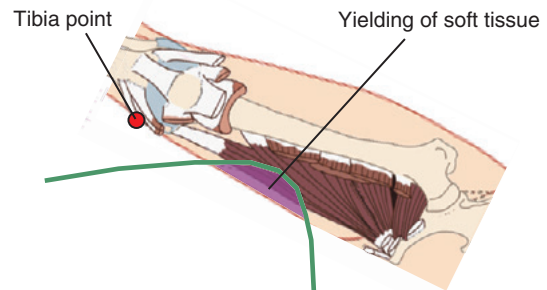


Fig. 9 Thigh posture in actual condition

shown in Fig. 10, and the measuring instrument was fixed on a stand with wheels that moved in only a single axial direction.

Markings were made at 10 mm intervals starting from the tibia point on the center axis on the inside of the thigh, and pressure was applied by the indentation hardness tester pressing in toward the femur at each marking point. The applied pressure was such that test subjects did not feel strong pain.

#### 4.3.3. Results

Figure 11 shows a graph plotting the average values of all test subjects on the same coordinate axes as those shown in Fig. 8. These results are defined as the interference limit  $G(x)$ . This graph also shows the results for motorcycle C, which had the largest interference depth  $F(a)$  in Section 4.2, and motorcycle E, which had a good rating. In addition, even for the same pointed shape, pain was less likely felt as the difference between the interference limit  $G(x)$  and the interference depth  $F(a)$  increased, so  $G(a) - F(a)$  was defined as the interference tolerance  $\delta(a)$ .

Motorcycle C greatly exceeded the interference limit  $G(x)$ . When substituted to the actual condition, the tibia point did not contact the knee-grip surface, and the knee was detached. To express the actual condition using Fig. 11, the interference tolerance  $\delta(a)$  should be 0 or more, i.e.,  $\delta(a) \geq 0$ , so the hip joint of the rider model was abducted to satisfy this condition. Figure 12 shows a graph plotting

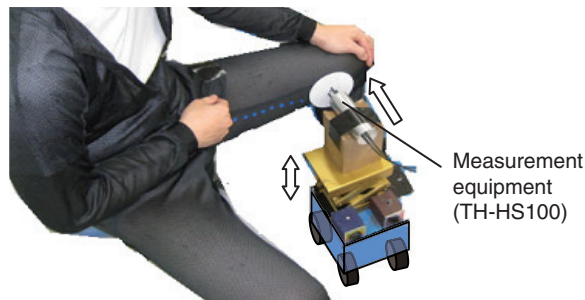


Fig. 10 Measurement of yielding depth

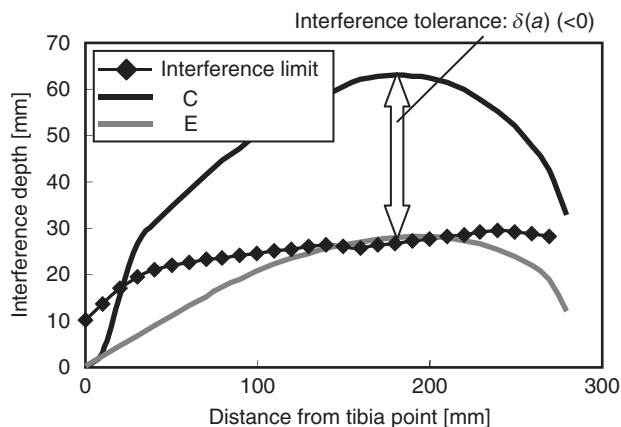


Fig. 11 Results of interference limit

the interference depth at this time. As shown in Fig. 12, the position where the thigh began to contact the knee-grip surface (minimum non-contacting length) was 100 mm from the tibia point in the direction of the groin. According to the results in Section 4.2, the minimum non-contacting length threshold value is 80 mm, so it is thought that motorcycle C received a low rating as a result of exceeding this threshold.

#### 4.4. Derivation of Multiple Regression Formulas by Subjective Rating of Model Surface Shapes

Subjective rating was performed using model surface shapes, and multiple regression analysis was performed to determine the parameters that express a feeling of discomfort in the thigh during knee gripping and to derive a predictive formula that expresses the discomfort level.

##### 4.4.1. Test subjects

The test subjects were the same as those in Section 4.2.

##### 4.4.2. Experimental method

Model surface shapes were created that can express the difference between the maximum interference depth and the degree of protrusion. The model surface shapes had a saucer shape created by cutting a sphere. A total of nine different model surface shapes were prepared using three height specifications (10 mm, 12.5 mm, 15 mm) enabling the maximum interference depth to be changed, and three radius specifications (60 mm, 80 mm, 90 mm) enabling the degree of protrusion to be changed.

The test subjects sat on a motorcycle with a flat plate attached to the knee-grip surface to eliminate dependence on the existing knee-grip surface shape. The saucer-shaped model surface was attached to the flat plate so that the tip of the model surface contacted the specified thigh position when the test subjects gripped with their knees. Figure 13 shows the experimental conditions. This method was used to subjectively rate each of the total 27 patterns comprising different thigh positions (tibia point, middle of thigh, groin area), different maximum heights (3 types) and different radii (3 types), arranged in random order using a random number table.

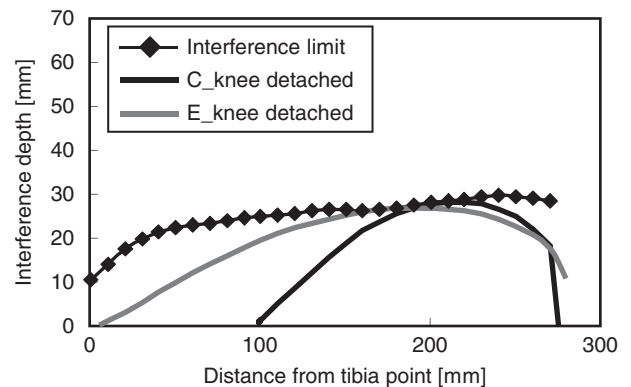


Fig. 12 Results adjusted by interference limit

Table 5 Verification of multiple regression formulae

| Position on thigh         |                        | Tibia      | Middle of thigh | Groin     |
|---------------------------|------------------------|------------|-----------------|-----------|
| Correlation coefficient R |                        | 0.93       | 0.99            | 0.95      |
| Significance level F      |                        | 0.01<br>** | 0.00<br>**      | 0.03<br>* |
| P-value                   | Interference tolerance | -          | 0.02            | 0.02      |
|                           | Degree of protrusion   | 0.01       | 0.00            | 0.04      |

Table 6 Multiple regression formulae for each position

| Position                             | Multiple regression formulae                                                                             |
|--------------------------------------|----------------------------------------------------------------------------------------------------------|
| Tibia<br>$0 \leq a \leq 60$          | Point = $-2.3 \times [\text{Degree of protrusion}] + 6.02$                                               |
| Middle of thigh<br>$60 < a \leq 160$ | Point = $-0.56 \times [\text{Degree of protrusion}] + 0.14 \times [\text{Interference tolerance}] + 3.4$ |
| Groin<br>$160 < a$                   | Point = $-0.35 \times [\text{Degree of protrusion}] + 0.1 \times [\text{Interference tolerance}] + 3.1$  |

#### 4.4.3. Results

The test conditions were reproduced on a computer, and the interference tolerance  $\delta(a)$  and the degree of protrusion were derived for each of the 27 patterns using the method described in Chapter 4 above. Table 5 shows the results of performing multiple regression analysis for each thigh position using the subjective rating values as the dependent variable and the interference tolerance  $\delta(a)$  and degree of protrusion as independent variables. The multiple correlation coefficients showed an extremely strong correlation of 0.9 or more. In addition, P-values were calculated in order to check the significance of independent variables, obtaining both interference tolerance and degree of protrusion of less than 5%, so these variables are significant at the 5% level of significance. Therefore, it can be said that interference tolerance and degree of protrusion are necessary and sufficient as evaluation parameters that express the feeling of thigh discomfort. In addition, subcutaneous fat and other tissues differ according to the thigh position, so a multiple regression formula was obtained for each position. Therefore, the multiple regression formula should be selected according to the point “a” value that results in the maximum interference depth. Table 6 shows the obtained multiple regression formulae.

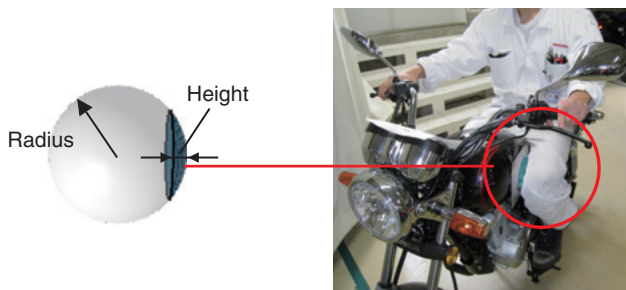


Fig. 13 Test to determine multiple regression formulae

## 5. Verification of Validity

To confirm whether the multiple regression formulae derived from the experiment results in Chapter 4 and minimum non-contacting length judgment using the interference limit correctly express the feeling of thigh discomfort during knee gripping, verification was performed using the shape data for 15 different motorcycles that had been rated by running tests.

### 5.1. Verification Method

Five motorcycles rated in running tests as producing a feeling of thigh discomfort, five motorcycles rated as producing some thigh discomfort, and five motorcycles rated as producing no thigh discomfort were selected as the 15 motorcycles.

The mock-up surface data of each motorcycle was imported, and rider models were added to the data using the method described in Chapter 2. The rider model seated positions were the normal position and front position, and the rider physiques used the JM50%tile, JM95%tile and JF5%tile models to simulate different heights.

The interference tolerance and degree of protrusion were derived from these models and substituted into the multiple regression formula corresponding to the maximum point “a” value (Table 6). In addition, when the interference depth exceeded the interference limit, the minimum non-contacting length was derived.

### 5.2. Verification Results

Figure 14 shows the predicted thigh discomfort values obtained as a result of calculations for the JM50%tile rider model in the front position. Note that when the minimum non-contacting length exceeded the threshold value of 80 mm, one point was assigned as the predicted value. Likewise, comparison of the results for each physique confirmed that the feeling of thigh discomfort could be estimated computationally with 93% accuracy by using the derived multiple regression formula and minimum non-contacting length.

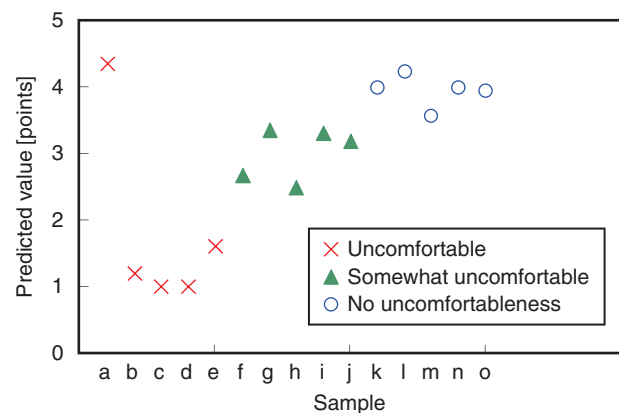


Fig. 14 Results of validity check

The results for motorcycle model “a” diverged from the predicted value, and a survey of the feeling of discomfort produced the response of “loose feeling”. Motorcycle model “a” is within the recommended area established in Chapter 3, and the leg posture should enable exertion of sufficient gripping force. However, there is insufficient interference near the groin, which is surmised to have lowered the secure feeling. The predictive formula derived in this study enables judgment when the knee-grip surface interferes excessively with the thigh, but is less reliable when there is insufficient interference. This is thought to be the reason why the result diverged from the predicted value.

## 6. Conclusion

Motorcycle knee-grip simulation technology was constructed using a computer mannequin and ergonomic techniques, and the following was achieved.

- The recommended relative positions of the center of the foot peg and the knee contact area on the knee-grip surface were determined that result in a leg posture that enables exertion of sufficient gripping force.
- Interference tolerance and degree of protrusion were defined as parameters that express the feeling of knee-grip discomfort, and a predictive formula was derived. This enabled computational evaluation of the feeling of knee-grip discomfort from the mock-up surface data.

## References

- (1) Koyano, M., Nakamura, T., Sunaga, T.: Seating comfort anticipation of the motorcycle seat by body pressure distribution simulation, JSAE Annual Congress (Autumn), 20045648 (2004)
- (2) Yoshikawa, S., Kato, I.: Mechanical characteristics of human body surface and its measurement method, Ningenkogaku, Vol. 11, No. 1, p. 23-28 (1975)
- (3) Yonemoto, K.: Anthropometry for car design, Ningenkogaku, Vol. 6, No. 1, p. 15-18 (1970)
- (4) Research institute of human engineering for quality life: Japanese body size data book 2004-2006
- (5) Open Ergonomics Ltd.: ADULTDATA
- (6) Ishikawa, K., Onuma, G., Usuzumi, T., Tokunaga, K., Nakashima, M.: Santeiban Seni, Tokyo Denki Daigaku Shuppankyoku (1969) (in Japanese)
- (7) Murayama, M., Nosaka, K., Yoneda, T., Minamitani, K.: Change in hardness of the human elbow flexor muscles after eccentric exercise, Eur J Appl Physiol, Vol. 82, p. 361-367 (2000)

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