STUDY ON VISIBILITY AND DISCOMFORT GLARE OF ADAPTIVE FRONT LIGHTING SYSTEM (AFS) FOR MOTORCYCLES

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ABSTRACT

When a motorcycle is driven on a curved road, the motorcycle headlamp inclines horizontally as the motorcycle body banks, and the area illuminated by the headlamp becomes limited. Therefore, minimizing the horizontal inclination of the headlamp would improve the visibility. This study was conducted to clarify the effects of a system to adjust the horizontal inclination of the motorcycle headlamp (hereafter, “motorcycle AFS”) on visibility for the rider, and to examine the side-effects of the motorcycle AFS (e.g., discomfort glare for oncoming drivers).
The study included the following two parts:
(1) A simulation survey and an actual driving survey to test the visibility demonstrated that a motorcycle AFS enhances visibility for the rider while the motorcycle is being driven on curved road. When the horizontal inclination of the headlamp is adjusted by the same or greater amount than the bank angle of the motorcycle body, the visibility evaluation scores are equal to or above the just acceptable level. However, when the adjustment amount is less than the bank angle, the visibility evaluation scores are below the just acceptable level.
(2) A simulation survey and an actual driving survey to evaluate the discomfort glare showed that when the horizontal inclination of the headlamp is adjusted by the same or smaller amount than the bank angle, the glare evaluation scores are equal to or above the just acceptable level. However, when the adjustment amount is more than the bank angle, the glare evaluation scores are below the just acceptable level.
Based on the results obtained in this study, the following technical requirement is proposed for the motorcycle AFS:
"A horizontal inclination adjustment system (HIAS) may be installed. However, the adjustment amount of horizontal inclination shall not exceed the vehicle's bank angle."

INTRODUCTION

In recent years, adaptive front lighting systems (AFS) have been increasingly introduced for four-wheeled vehicles. The AFS is designed to improve the visibility for the driver in accordance with the driving conditions by controlling the optical axis of headlamps in coordination with steering wheel operation and/or by using a supplementary light source in addition to existing headlamps.
With regard to the motorcycle AFS, Japanese motorcycle manufacturers have presented AFS-mounted prototype vehicles as part of the Advanced Safety Vehicle (ASV) Project, which is being implemented by Japan’s Ministry of Land, Infrastructure and Transport. However, the motorcycle AFS has not yet been released.
In the case of a motorcycle headlamp, when a motorcycle is driven on a curved road, the motorcycle headlamp inclines horizontally as the vehicle body banks, and the area illuminated by the headlamp becomes limited. The range of road illuminated by the headlamp in the direction of travel tends to become narrow because the headlamp horizontally inclines with the vehicle body in curves.

Therefore, the visibility could be improved if the horizontal inclination angle of the headlamp (hereafter, “inclination angle”) could be adjusted to keep the cut-off line horizontal (Figure 1). In order to obtain the data required to draw up motorcycle AFS regulations, this study examined the effect of inclination angle on improving the visibility for riders and on the discomfort glare for oncoming vehicle drivers.

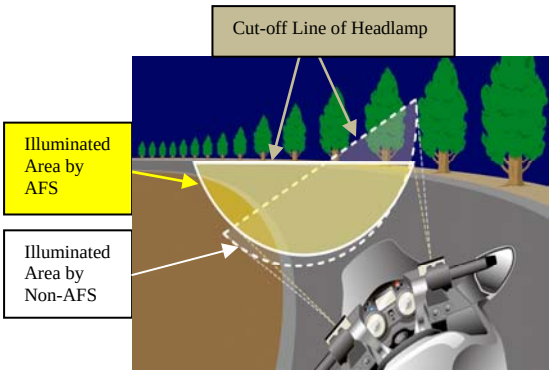

Figure 1. Illuminated area by AFS headlamp and non-AFS headlamp

MEASUREMENT OF THE INCLINATION ANGLE AND THE AIMING DIRECTION OF A MOTORCYCLE HEADLAMP IN A CURVE

Objective

The objective of this research item was to measure the inclination angle and the aiming direction of a motorcycle headlamp in a curve.

Method

Test Vehicle and CCD Cameras - The test vehicle was a 400 cc class motorcycle fitted with a CCD camera at the usual headlamp position (850 mm above the ground). The images taken by the onboard camera (Figure 2) and the images taken by the CCD camera fixed on the ground (Figure 3) were analyzed to determine the inclination angle and the aiming direction of the motorcycle headlamp. These two images were synchronized by LED lamps.

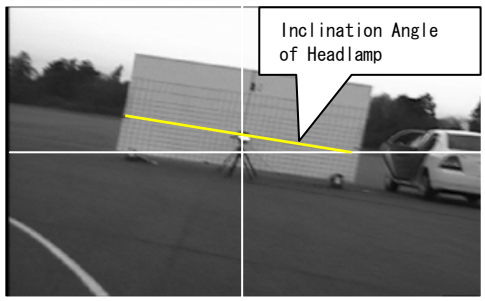

Figure 2. Image by motorcycle mounted CCD camera

Figure 3. Image by CCD camera fixed on the ground

Test Course - While a motorcycle was driven counterclockwise around a circular test track (marked with white lines of different radii; see Figure 4), the inclination angle and the aiming direction of the motorcycle headlamp in a left curve were measured.

Figure 4. Test course (circular test track)

Measurement Conditions - Four radii of lane curvature were used: 30 m, 50 m, 70 m and 140 m.
The vehicle speeds were determined by the method for calculating minimum radii in "Interpretation and implementation of the road construction ordinance [1)]."

Test Riders - The test riders were four males who frequently rode motorcycles for test work.

Number of Measurements - The measurements were taken 20 times under each measurement condition (4 riders x 5 runs).

Results

Based on the analysis results of the 20 rounds for each measurement condition, the median values of the inclination angle of the motorcycle headlamp and the aiming direction for that inclination angle were obtained as shown in Table 1.

Table 1. Results of headlamp inclination angle and aiming direction measurement

Radius	Vehicle Speed	Headlamp		
		Inclination Angle	Aiming Direction (Degree)	
			Y	Z
30m	30km/h	12.9°	1.7	0.3
50m	40km/h	13.3°	3.6	0.2
70m	50km/h	15.2°	0.5	0.2
140m	60km/h	13.4°	1.3	0.4

Y : + Indicates rightward. Z : + Indicates upward.

SIMULATION SURVEY ON VISIBILITY OF MOTORCYCLE AFS

Objective

The objective of this computer simulation was to compare visibility performance among headlamps with fixed inclination angle adjustment, a headlamp whose cut-off line was adjusted to remain parallel to the ground at all times (AFS headlamp), and a conventional headlamp.

Method

Visual targets were assumed to be visible by the rider if they were located below the cut-off line of the motorcycle headlamp's passing beam (i.e. within the reach of intense headlamp light). Therefore the visibility distance was determined based on the criterion that the visual target is considered visible when it is located in the range below the cut-off line of the headlamp.

Headlamps - A simulation was conducted on the headlamp's passing beam presenting a symmetrical lighting pattern with a horizontal cut-off line. The headlamp aiming direction was set with a cut-off line 1% (0.57 degrees) downward of the horizontal.

Simulation Conditions - The simulation was conducted for the condition where the motorcycle headlamp inclination angle was adjusted and for the conditions where the inclination angle was not adjusted. A total of four adjustment conditions were set: three conditions with the fixed inclination angle adjustments (7.5 degrees, 15 degrees and 22.5 degrees) and one condition with the cut-off line adjusted to remain parallel to the ground (AFS headlamp).

Driving Course and Visual Targets - The motorcycle driving course and the visual targets are shown in Figure 5. The lane width was 3.5 m, and the motorcycle was driven along the center of the left lane on a left curve. The distance was indicated based on the circular distance along the lane center.
Four radii of lane curvatures were used: 30 m, 50 m, 70 m and 140 m.
Three visual targets were set: lane edge line, lane center, and center line in the left curve.

Range of Calculation - The range of calculation was determined to be that where the distance between the motorcycle headlamp location and the visual target reaches 1/4 of the circle or 100 m. That is, the calculation was performed using the 47 m range for the radius of 30 m, the 78 m range for the radius of 50 m, and the 100 m range for the radii of 70 m and 100 m.

Input Data - The input data necessary for the calculation (the inclination angle and the aiming direction of the motorcycle headlamp) as shown in Table 1 were used.

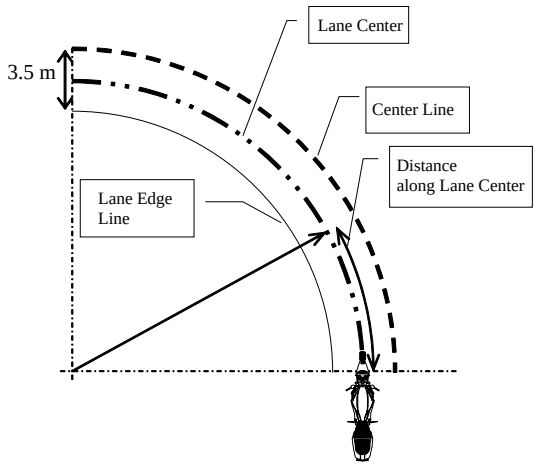

Figure 5. Driving course and visual targets

Results

The results of simulating motorcycle AFS visibility are shown in Table 2.
The ground angle is indicated as negative when the inclination angle adjustment of the motorcycle headlamp is smaller than the bank angle of the vehicle body, as zero when they are equal, and as positive when the inclination angle adjustment is larger (hereafter the same applies).
Compared with the case in which the inclination angle is not adjusted (= 0 degree), the cut-off line reaching distance becomes longer when the inclination angle is adjusted.
When the inclination angle adjustment is 22.5 degrees (with the positive ground angle) and at the AFS condition (with the zero ground angle), all the visual targets are located below the cut-off line.
Assuming that an acceptable visibility distance is 40 m or longer, all the visual targets are within the acceptable range when the inclination angle adjustment is 15 degrees, 22.5 degrees and at the AFS condition.
Consequently, the visibility for the rider is improved by adjusting the headlamp inclination angle in a curve.

In particular, when the adjustment is the same as the bank angle of the vehicle body (with zero ground angle) or higher (with positive ground angle), the visibility is greatly improved.

Table 2. Results of visibility simulation for headlamp inclination angle adjustment (Distance between headlamp and cut-off line : m)

Radius	Vehicle Speed	Headlamp		Visual Target		
		Inclination Angle Adjustment	Ground Angle (Degree)	Lane Edge	Lane Center	Center Line
30m	30km/h	0°	−12.9	9	13	16
		7.5°	−5.4	19	21	23
		15°	2.1	○	○	○
		22.5°	9.6	○	○	○
		AFS	0	○	○	○
50m	40km/h	0°	−13.3	9	15	18
		7.5°	−5.8	20	23	26
		15°	1.7	○	○	○
		22.5°	9.2	○	○	○
		AFS	0	○	○	○
70m	50km/h	0°	−15.2	11	18	23
		7.5°	−7.7	21	25	29
		15°	−0.2	95	95	94
		22.5°	7.3	○	○	○
		AFS	0	○	○	○
140m	60km/h	0°	−13.4	18	26	33
		7.5°	−5.9	36	41	46
		15°	1.6	○	○	○
		22.5°	9.1	○	○	○
		AFS	0	○	○	○

○ : Indicate all visual targets are below cut-off line.

▭ : Indicate cut-off lines are over 40m ahead from headlamp.

ACTUAL DRIVING SURVEY ON VISIBILITY OF MOTORCYCLE AFS

Objective

An actual driving survey was conducted to confirm the results of the computer simulation survey by comparing the visibility performance among headlamps with fixed inclination angle adjustment, a headlamp whose cut-off line was adjusted to remain parallel to the ground at all times (AFS headlamp), and a conventional headlamp.

Method

Test Motorcycles - Two 250 cc class motorcycles, two 400 cc class motorcycles and a 1200 cc class motorcycle were used (Figure 6).

Headlamps - Five motorcycle halogen headlamps conforming to the light distribution requirements for motorcycles (125 cc or more) of ECE R 113 were used. The headlamp heights

were 850 mm above the ground. Passing beams with symmetrical light distributions (horizontal pattern cut-off line) were evaluated.
The following five headlamp conditions were used:
(1) Inclination angle is not adjusted (0 degree)
(2) Fixed inclination angle adjustment of 7.5 degrees
(3) Fixed inclination angle adjustments of 15 degrees
(4) Fixed inclination angle adjustment of 22.5 degrees
(5) Prototype AFS headlamp with the cut-off line adjusted to remain parallel to the ground at all times

(Non-AFS headlamp) **(AFS headlamp)**

Figure 6. Test motorcycles and headlamps

Driving Courses - The circular test track (Figure 4), an urban test road and a middle-speed oval test track were used for the visibility evaluation. The motorcycles were driven counterclockwise around the circular test track. Four radii of lane curvature were used: 30 m, 50 m, 70 m and 140 m.

Driving Methods and Vehicle Speed - Subjects wearing helmets (light transmittance of windshields was around 90%) drove the motorcycles, and were instructed to drive at the following speeds.
(1) Circular test track: Same as Table 1.
(2) Urban test road and middle-speed oval test track: Within the speed limits (maximum speed was 60 km/h).

Headlamp Visibility Evaluation - After each driving, the subjects reported on the headlamp visibility using the following evaluation scale:

1: Inadequate
2: Somewhat inadequate
3: Just acceptable
4: Somewhat adequate
5: Adequate

A value of 3.0 is the “just acceptable” level, so 3.0 or higher means an acceptable or adequate level of visibility.

Subjects - Nine subjects participated in the test on the circular test track, and 8 subjects participated in the test on the urban test road and the middle-speed oval test track. All of them were lamp experts.

Results

The average visibility evaluation values rated by the 9 or 8 subjects are shown in Figures 7 and 8. A significant difference between the evaluation value for when the inclination angle of the headlamp was not adjusted (0 degree) and that when it was adjusted is indicated as * ($p<0.05$) or ** ($p<0.01$).

Visibility Evaluation on a Circular Test Track - The test results on a circular test track are summarized as follows (Figure 7).
(1) The visibility evaluation value is higher when the inclination angle is adjusted or at the AFS condition compared with when the headlamp is not adjusted (0 degree), with a significant difference at all radii.
(2) The visibility evaluation value at the AFS condition is highest.
(3) The visibility evaluation value is higher when the headlamp inclination angle adjustment is bigger.
(4) The visibility evaluation value for the 0 degree condition is below the acceptable borderline of 3.0 at all radii. But the visibility evaluation value for 15 degrees, 22.5 degrees and the AFS condition are within the acceptable range at all radii.

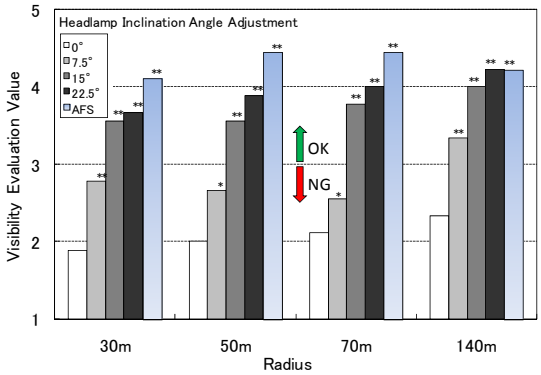

Figure 7. Visibility evaluation on the circular test track

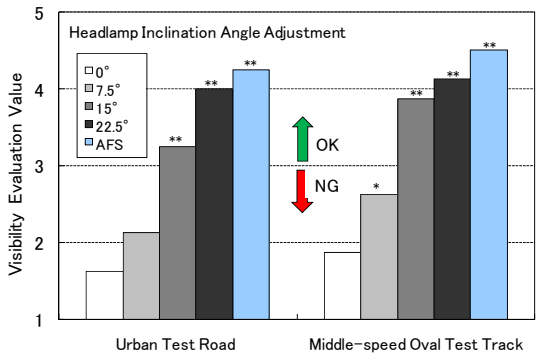

Figure 8. Visibility evaluation on the urban test road and the middle-speed oval test track

<u>Visibility Evaluation on the Urban Test Road and the Middle-speed Oval Test Track</u> -
The test results on the urban test road and the middle-speed oval test track are summarized as follows (Figure 8).
(1) Both on the urban test road and the middle-speed oval test track, the visibility evaluation value for 15 degrees, 22.5 degrees and the AFS condition is significantly higher compared with the case in which the inclination angle of the headlamp is not adjusted (0 degree).
(2) Both on the urban test road and the middle-speed oval test track, the visibility evaluation value at the AFS condition is highest.
(3) The visibility evaluation value is higher when the headlamp inclination angle adjustment is bigger.
(4) Both on the urban test road and the middle-speed oval test track, the visibility evaluation values for the 0 degree and 7.5 degree conditions are below the acceptable borderline of 3.0. But the visibility evaluation value for the 15 degrees, 22.5 degrees and AFS conditions are within the acceptable range.
Consequently, it was clarified that the visibility for the rider is improved by adjusting the headlamp inclination angle in a curve.
In particular, the 15 degrees, 22.5 degrees and AFS headlamp conditions greatly improve the visibility in different road conditions.
The results of the computer simulation survey were confirmed by the actual driving survey on headlamp visibility.

SIMULATION SURVEY ON GLARE OF MOTORCYCLE AFS

Objective

The objective of this computer simulation was to compare the glare for the oncoming vehicle driver among headlamps with fixed inclination angle adjustment, a headlamp whose cut-off line is adjusted so that it remains parallel to the ground at all times (AFS headlamp), and a conventional headlamp.

Method

The range of the motorcycle headlamp glare for the oncoming vehicle driver was determined on the criterion that the glare is considered present when the eye location (“eyepoint”) of the oncoming vehicle driver is below the cut-off line of the motorcycle headlamp’s passing beam (that is, when the relatively strong light of the headlamp reaches the eyepoint).
The headlamps, aiming direction and inclination angle adjustment conditions used in the glare simulation are the same as those described in "Simulation survey on visibility of motorcycle AFS".
The input data necessary for the calculation (the inclination angle adjustment and the aiming direction of the headlamp) as shown in Table 1 were used.

Driving Course and Driver Eye Location - The motorcycle driving course and the oncoming car driver's eyepoint location are shown in Figure 9.
The lane width is 3.5 m, and the motorcycle was driven along the center of the left lane on a left curve or right curve. The oncoming vehicle driver's eyepoint location was set at the standard eyepoint location of the drivers of passenger cars driving along the center of the oncoming lane (1.35 m outward from the center line and 1.1 m above ground). The indication of distance and the conditions of radii of curves are the same as those described in "Simulation survey on visibility of motorcycle AFS".

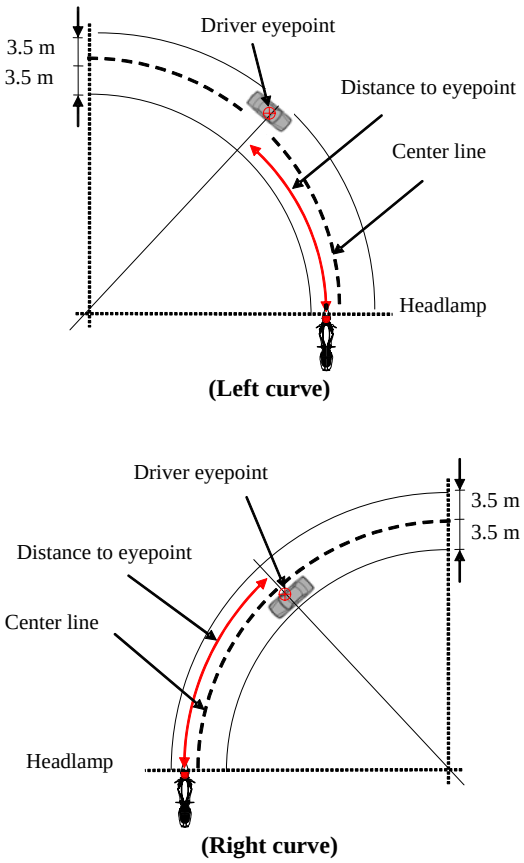

Figure 9. Driving course and driver eyepoint location

Range of Calculation - The range of calculation was determined to be the range where the distance between the motorcycle headlamp location and the eyepoint reaches from 30 m to 1/4 of the circle or from 30 m to 100 m. That is, the calculation was performed using the 30–47 m range for the radius of 30 m, the 30–78 m range for the radius of 50 m, and the 30–100 m range for the radii of 70 m and 100 m.

Results

The results of the simulation of motorcycle AFS glare are given in Table 3. Here, the ranges where the oncoming vehicle driver's eyepoints are below the motorcycle headlamp cut-off line are considered.
The eyepoints are located above the motorcycle headlamp cut-off line without exception when the headlamp inclination angle adjustment is 0 degrees (with the negative ground angle), 7.5 degrees (with the negative ground angle), and at the AFS condition (with the zero ground angle). Therefore, the oncoming vehicle driver receives no glare under all these conditions.
For the 15 degree headlamp inclination angle adjustment, when the ground angle is negative the oncoming vehicle driver receives no glare since the driver eyepoint is above the cut-off line, but when the ground angle is positive the oncoming vehicle driver receives glare since the driver eyepoint is below the cut-off line of headlamp.
For the 22.5 degree headlamp inclination angle adjustment, the ground angle is positive for all radii, and the oncoming vehicle driver receives glare since the driver eyepoint is below the cut-off line of the headlamp.
In summary, the oncoming vehicle driver receives no glare when the headlamp inclination angle is adjusted to the same or lower level as the vehicle body bank angle, but does receive glare when it is adjusted to a higher level.

Table 3. Results of glare simulation for headlamp inclination angle adjustment (Range where driver eyepoints are below cut-off line: m)

Radius	Vehicle Speed	Headlamp		Curve	
		Inclination Angle	Ground Angle (Degree)	Left Curve	Right Curve
30m	30km/h	0°	−12.9	○	○
		7.5°	−5.4	○	○
		15°	2.1	35～47	30～47
		22.5°	9.6	30～47	30～47
		AFS	0	○	○
50m	40km/h	0°	−13.3	○	○
		7.5°	−5.8	○	○
		15°	1.7	56～78	50～78
		22.5°	9.2	30～78	30～78
		AFS	0	○	○
70m	50km/h	0°	−15.2	○	○
		7.5°	−7.7	○	○
		15°	−0.2	○	○
		22.5°	7.3	33～100	30～100
		AFS	0	○	○
140m	60km/h	0°	−13.4	○	○
		7.5°	−5.9	○	○
		15°	1.6	○	○
		22.5°	9.1	47～100	30～100
		AFS	0	○	○

○ : Indicate driver eyepoints are always above cut-off line.

x～y : Indicate the range (m) where eyepoints are below cut-off line.

ACTUAL DRIVING SURVEY ON GLARE OF MOTORCYCLE AFS

Objective

The objective of this actual driving survey was to confirm the results of the computer simulation survey comparing glare for the oncoming vehicle driver among headlamps with fixed inclination angle adjustment, a headlamp whose cut-off line is adjusted so that it remains parallel to the ground at all times (AFS headlamp), and a conventional headlamp.

Method

Test Motorcycles and Headlamps - The test motorcycles and headlamps used in this survey are the same as those in "Actual driving survey on visibility of motorcycle AFS".

Driving Course - The middle-speed oval test track was used for glare evaluation. Motorcycles were driven clockwise on a right curve of radius 180 m (Figure 9).

Evaluation Method and Vehicle Speed - Subjects in the driver seat of the stationary car were instructed to look ahead and to evaluate the glare of the oncoming motorcycle headlamp. The observation was performed between 100 m and 30 m ahead from the driver eyepoint.

Headlamp Glare Evaluation - After each driving, subjects reported on headlamp glare using the following De Boer's 9-point scale, which is widely used for evaluating discomfort glare:

1: Unbearable glare
2:
3: Glare obstructing driving
4:
5: Permissible maximum glare (just acceptable)
6:
7: Fully permissible glare
6:
9: No perception of glare

A value of 5.0 is the "just acceptable" level, so 5.0 or higher means an acceptable or adequate level of glare.

Subjects - A total of 8 subjects participated. All of them were lamp experts.

Results

The average glare evaluation values rated by the 8 subjects are shown in Figure 10.
A significant difference between the evaluation value for the condition in which the inclination angle of the headlamp is not adjusted (0 degree) and for the condition in which the inclination angle is adjusted is indicated as * ($p<0.05$) or ** ($p<0.01$).
The test results are summarized as follows.
(1) Compared with the case in which the inclination angle of the motorcycle headlamp is not adjusted (0 degree), the glare evaluation value is significantly lower when the inclination angle is adjusted to 7.5 degrees, 15 degrees and 22.5 degrees.
(2) The glare evaluation value is lower when the headlamp inclination angle adjustment is bigger.
(3) The glare evaluation value for the 0 degree, 7.5 degrees and AFS condition is within the

acceptable range, but the glare evaluation values for 15 degrees and 22.5 degrees are below the acceptable level. In this driving situation (on a curve of radius 180 m at 60 km/h), the bank angle of the motorcycle body is estimated to be 13 degrees. Therefore, for the 15 degrees and 22.5 degrees conditions, the headlamp inclination angle adjustment exceeds the bank angle of the vehicle body (with the positive ground angle),

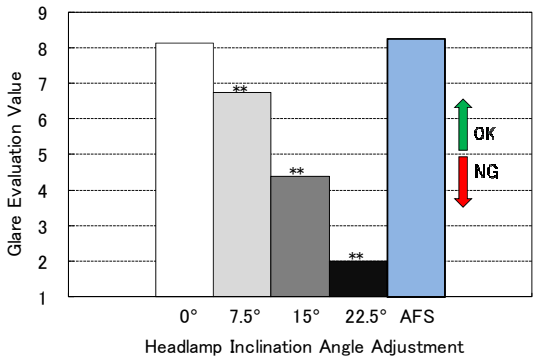

Figure 10. Glare evaluation for headlamp inclination angle adjustment

Hence, the oncoming vehicle driver receives glare within the acceptable range when the headlamp inclination angle is adjusted to the same or lower level as the vehicle body bank angle, but does receive unacceptable glare when it is adjusted to the level higher than the vehicle body bank angle.

CONCLUSION

The results obtained in the "Simulation survey on visibility of motorcycle AFS" and "Simulation survey on glare of motorcycle AFS" are summarized in Table 4.
In the visibility evaluation, it is assumed that visibility is acceptable if the cut-off line of the headlamp light reaches 40 m or longer forward at the lane edge line.
In the glare evaluation, it is assumed that oncoming vehicle drivers receive no glare when their eyepoints are located above the headlamp cut-off line.

In the overall synthetic evaluation of the motorcycle headlamp performance in curves, it is deemed satisfactory if both visibility and glare are satisfied.
The results of the study on the motorcycle AFS visibility and glare are summarized as follows:
(1) It was found that the headlamp visibility is improved by adjusting the headlamp inclination angle in curves. The motorcycle headlamp visibility in curves was found to be within the acceptable range when the headlamp inclination angle is adjusted to equal the vehicle body bank angle (with the zero ground angle) or to the level higher than the vehicle body bank angle (with the positive ground angle).
(2) It was found that the oncoming vehicle driver receives no glare when the headlamp inclination angle is adjusted to equal the vehicle body bank angle (with the zero ground angle) or less (with the negative ground angle), but does receive glare when adjusted to more than the vehicle body bank angle (with the positive ground angle).
(3) The overall synthetic evaluation of motorcycle AFS visibility and glare showed that, if the motorcycle headlamp inclination angle is adjusted in curves, it will be appropriate to use an adjustment angle that is close to the vehicle body bank angle but does not exceed it.

Table 4. Summary of visibility evaluation, glare evaluation and overall synthetic evaluation for motorcycle AFS

Radius	Vehicle Speed	Motorcycle Headlamp		Evaluation		
		Inclination Angle Adjustment	Ground Angle (Degree)	Visibiliy	Glare	Synthetic Evaluation
30m	30km/h	0°	−12.9		○	
		7.5°	−5.4		○	
		15°	2.1	○		
		22.5°	9.6	○		
		AFS	0	○	○	○
50m	40km/h	0°	−13.3		○	
		7.5°	−5.8		○	
		15°	1.7	○		
		22.5°	9.2	○		
		AFS	0	○	○	○
70m	50km/h	0°	−15.2		○	
		7.5°	−7.7		○	
		15°	−0.2	○	○	○
		22.5°	7.3	○		
		AFS	0	○	○	○
140m	60km/h	0°	−13.4		○	
		7.5°	−5.9		○	
		15°	1.6	○	○	○
		22.5°	9.1	○		
		AFS	0	○	○	○

○ : Indicate evaluation value is equal to or above just acceptable level.

Indicate evaluation value is below just acceptable level.

Furthermore, the validity of the results of the “Simulation survey on visibility of motorcycle AFS” and “Simulation survey on glare of motorcycle AFS” was also confirmed in the actual driving tests using the motorcycles with the inclination angle adjusted headlamps, a motorcycle with the prototype AFS headlamp and a motorcycle equipped with the conventional headlamp.

REQUIREMENT

Based on the results obtained in this study, the following technical requirement is proposed for the motorcycle AFS:
"A horizontal inclination adjustment system (HIAS) may be installed. However, the adjustment amount of horizontal inclination shall not exceed the vehicle's bank angle."

The formal document submitted to GRE by the expert from Japan proposed the amendment to Regulation No. 53 in order to introduce the requirements concerning the the vehicle's horizontal inclination angle adjustment-type headlamps installed on motorcycles [2)].

REFERENCES

[1] Japan Road Association. 2004. "Interpretation and Implementation of the Road Construction Ordinance," pp. 309-320.

[2] ECE/TRANS/WP.29/2009/4. January 2009. "Visibility of adaptive front-lighting system (AFS) for motorcycles and glare, Proposal for Supplement 11 to the 01 series of amendments to Regulation No. 53, Submitted by the expert from Japan".