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LONG LIGHTING SYSTEM FOR ENHANCED CONSPICUITY OF MOTORCYCLES

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ABSTRACT

The LONG (Longitudinal Oriented Normative time Gap compensation) concept describes a lighting system that enhances the conspicuity of motorcycles by enhancing the ability of oncoming drivers to evaluate the distance and speed of a motorcycle equipped with lighting in the LONG configuration. It is based on the hypothesis that a motorcycle observed at the same distance and speed as an automobile may be perceived farther away and traveling more slowly than the automobile, because of the motorcycle's higher lamp location and narrower lighting layout compared with that of an automobile. To address this the LONG configured are spread farther apart along a vertical axis compared to the relatively tightly grouped lighting layout found on a typical motorcycle. Knowledge of cognitive psychology is applied to the LONG system. To test the hypotheses behind the LONG concept, it has been evaluated by measuring critical time gap in right-turn across path scenario (in left traffic right-of-way countries). It is shown that motorcycles with the system have conspicuity on a level comparable to automobiles by measuring critical time gaps of about 20 experimental subjects. The effects of both the layout of the lighting and luminous intensity dependence are also reported.

INTRODUCTION

It was reported that accident studies provided evidence that motorcycles were not perceived easily by road-users [1].In order to enhance detectability of motorcycles in during daylight hours, the daytime use of headlamps on motorcycles began to spread in the late 1960s in the United States. It became mandatory in Japan in 1998. Daytime motorcycle lighting requirements spread widely, even in Europe, later on. This measure aimed at enhancing "detectability" among elements of conspicuity and did not aim at enhancing "evaluation of distance and speed" by oncoming traffic that is another element of conspicuity. As a matter of course, this measure does not show any benefits of reducing collisions during nighttime hours. Sugawara et al. reported that the analysis of the fatal motorcycle accidents (in which car drivers are responsible) from the Annual Traffic Accident Statistical Database of 1998, showed that misperception of distance or speed of motorcycles was, together with failure of the car driver to be aware of motorcycles, a primary factor in accidents [2]. (Figure 1) Donne pointed out that this represents many collisions resulting from misperception of the distance or speed of the motorcycle involved in the crash in England [1]. In order to reduce these misperceptions of distance and speed, the LONG lighting system is being proposed to enhance the conspicuity of motorcycles by enhancing the ability of oncoming drivers to judge both the distance and speed of a motorcycle.

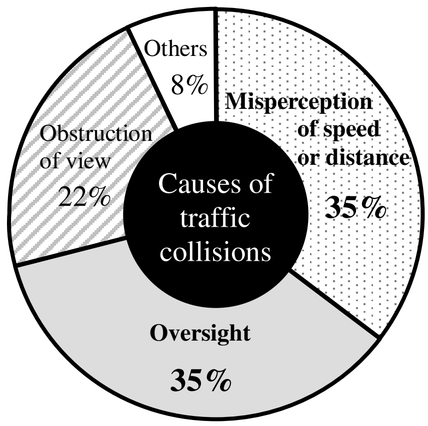

Figure 1. Analysis of motorcycle traffic accidents in Japan (T. Sugawara et al., 2006)

LONG LIGHTING SYSTEM

Fundamental Concept

We reported that there was the possibility that a lighting system can help to equalize conspicuity of various types of vehicles [3]. If some vehicles have higher conspicuity than other vehicles, the conspicuity of other vehicles may fall on a relative basis. The previous study aimed at reducing this effect. It may be desirable for motorcycles in mixed traffic to have conspicuity that is equivalent to that of automobiles. However the narrow frontal area and irregular outline of a motorcycle make it more difficult to recognize the whole body of a motorcycle than that of an automobile. Especially when viewed from the front a motorcycle headlamp and front position lamps are conspicuous (even if these lamps are turned off) and these lamps are considered as the keys to perception of motorcycle distance and speed.

If the separation between a subject and the horizon line in a visual field becomes longer, the subject is perceived as nearer. This describes a type of "perspective effect" [4] [5] [6]. Support for this hypothesis that human's visual recognition uses the angular declination below the horizon for distance judgment has been provided [7]. Ordinary motorcycles have a comparatively high layout position of headlamps and front position lamps, and don't have conspicuous lighting in the vicinity of a road surface. Therefore the distance to the motorcycle may be perceived as being further away than actual distance. In order to draw attention to the lower portion of motorcycles, lamps are located low and nearer to the road surface, for example in the lower part of the front fork. This is expected to allow an observer to more accurately judge the relative distance of a motorcycle. (Figure 2)

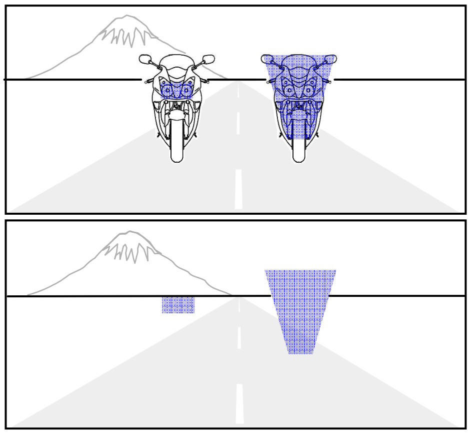

Figure 2. Principle of enhancing a sense of distance

Considering the approaching motorcycle as it relates to the optics of the observer, if the visual size of an approaching subject is small, the expanding size of the image on the retina of the observer would be smaller and the image on the retina would grow less quickly than a larger object, making it more difficult to accurately judge the speed of the approaching motorcycle. We reported that if the visual size of an approaching vehicle is large, the approaching speed could be recognized from a greater distance [8]. Since the headlamp and the front position lamp of ordinary motorcycles are located within a narrow area, the images on the retinas of the observer are small. Therefore it may be difficult to perceive the speed of the approaching motorcycle. In the case of ordinary motorcycles, vehicle height is comparatively tall, although the motorcycle's width is narrow. In order to emphasize the longitudinal size of the body, lamps are distributed longitudinally, spanning from a low position on the front fork to a high position on the body. This prevents the observer from recognizing the size of the body as being small, and aids the observer in more accurately judging the speed of an oncoming motorcycle. (Figure 3) It was reported that if the visual size of the subject is large, the sense of distance is also affected and the subject is perceived being closer to the observer [9]. (Figure 2)

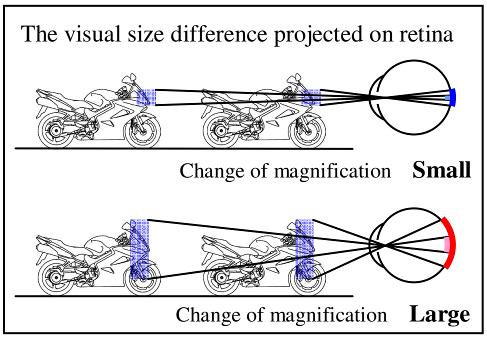

Figure 3. Principle of enhancing a sense of speed

Figure 4. LONG lighting system

Using these concepts, the LONG lighting system is proposed as a method to enhance motorcycles' conspicuity. Specifically, the LONG concept aids an observer's ability to more correctly judge both the distance and speed of an oncoming motorcycle, and allowing the observer to perceive approaching motorcycles more equally to an automobile. Figure 4 shows an example of a LONG frontal lighting configuration applied to a motorcycle. The name LONG comes from the emphasis on the longitudinal size of the motorcycle body and distribution of the lamps, as well as how the concept aids in compensating the critical time gap of motorcycles to become longer and more equivalent to that of automobiles.

Evaluation Methodology

The evaluation method is based on the belief that a driver synthetically judges the speed, distance of approaching vehicles and one's own speed, width of the road, etc., then uses this information to make a decision whether or not to turn to the right (in left-hand traffic right-of-way countries). This behavior is called the *gap acceptance behavior in right-turn across path scenarios*. If a vehicle approaches more quickly from the opposite direction, a driver chooses not to make a right-turn at a crossing. The passage time from the moment a driver chooses to give up until the approaching vehicle passes the driver's side is called the *critical time gap (CTG) in right-turn across path scenario* [10]. If CTG of various vehicles is compared, a quantitative measure of those vehicles' conspicuity relative to the observer's judgment of distance and speed can be made. The LONG lighting system has been quantitatively evaluated by measuring CTG in a right-turn across path scenario.

Figure 5 shows a schematic plan of a right-turn across path scenario of the type used in CTG measurements. The instruction to experimental subjects is that "you are waiting to make a right-turn at the crossing. If you judge that you must give up making the right-turn if a vehicle coming from the opposite direction approaches before you can safely make the right turn, please step on the brake pedal immediately". The velocity of the stimulus vehicle was set at 60 [km/h]. In order to control the stimulus to the experimental subject, the experimental subject starts the observation of the stimulus vehicle at the moment when the stimulus vehicle passes through the position of 150 [m] from the experimental subject. First, the experimental subject turns his eyes downward so that the experimental subject cannot see the stimulus vehicle. Next, the experimental subject begins observation of the stimulus vehicle at the moment when a signal sound from a sensor that senses a passing vehicle is heard. In order to minimize the learning effect on subjects, observation was stopped at the moment of stepping on the brake pedal by turning the subject's eyes downward again. The front grille of the subject's vehicle is equipped with a millimeter wave radar system. The speed and distance of the stimulus vehicle are simultaneously measured in a period of 0.1[sec] by the radar. The CTG is calculated from the speed and distance of the stimulus vehicle at the moment of stepping on the brake pedal. Five CTG measurements are continuously performed to the same stimulus vehicle, and the mean of five values is used as the value of the stimulus vehicle.

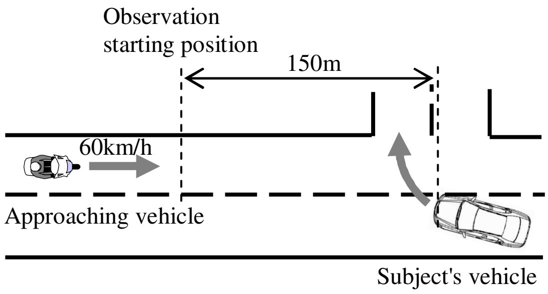

Figure 5. Schematic plan of *right-turn across path scenario*, as used in the study

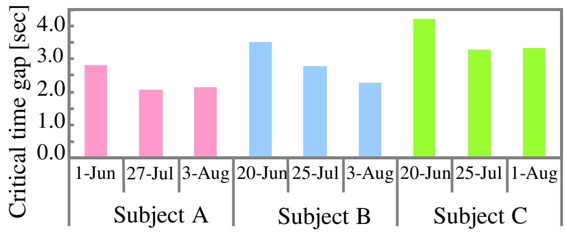

Figure 6. CTG of an ordinary motorcycle in nighttime

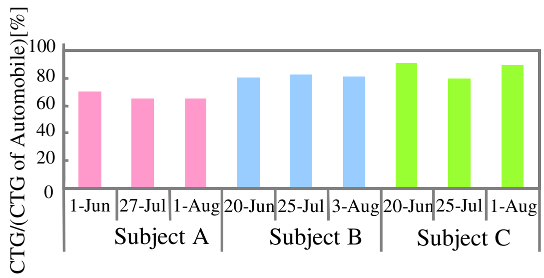

Figure 7. CTG ratio of an ordinary motorcycle compared to an automobile

Figure 6 depicts an example of the CTG measurement of an ordinary motorcycle in nighttime. It contains the results of three experimental subjects containing three data of the same motorcycle measured on different days. The standard deviation of the CTG for experimental subject A, B and C divided by the corresponding mean is 0.25, 0.30 and 0.21, respectively. There is considerable variation by measurement date in spite of the use of the same stimulus vehicle. Also in the past study, the variation in CTG [11] is referenced. Based on these results, it seems that CTG is not stable enough to independently represent conspicuity. We noted that the CTG of the automobile measured on the same day had the same variation as that of the motorcycle. The CTG ratios of the motorcycle to the automobile are shown in Figure 7. The standard deviation of CTG ratio of the experimental subjects A, B and C divided by the corresponding mean is 0.06, 0.02 and 0.10, respectively. The variation of the value by measurement date clearly becomes small. Therefore, it is possible to isolate conspicuity from the variation of each evaluation day by normalizing with the CTG of the automobile measured on the same day. The fundamental conceptual goal of the system is to make the conspicuity of motorcycles equivalent to that of automobiles. A comparison with automobiles supports this fundamental concept. We chose to utilize the CTG ratio of the motorcycle to the automobile when both are measured on the same day as the variable that evaluates the conspicuity based on distance and speed.

Enhanced Motorcycle Conspicuity

The enhanced conspicuity of motorcycles with a LONG lighting system is evaluated by CTG measurement. The photograph of the motorcycle used for a stimulus in the measurement is shown in Figure 8. This Honda XR250 Motard motorcycle is an on-road type with 250 [cc] engine displacement, with a LONG lighting system adapted to the front of the motorcycle. The large-sized amber-colored lamps (from a Honda CB1300SF) are used for the upper lamps of the system, and the small-sized lamps (from a Honda XR250) are used for the lower lamps. In order to change the luminous color to white, the original amber lenses were replaced with clear lenses. The height of two lower lamps (H) is set at 225 [mm], and the horizontal space between them is set at 300 [mm]. The upper lamps were set at a height of 950 [mm] above the lower lamps, and were horizontally spaced at 750 [mm] apart. In addition, a PWM circuit was added to allow the lamp luminous intensity of the LONG lighting system to be adjusted freely, is equipped. This motorcycle has special structural stays for headlamps so that many types of motorcycles can be simulated. This motorcycle is equipped with a single multi-reflector headlamp (55/60W for CB1300SF) at a height of 825 [mm]. The photograph of the automobile used for a stimulus in the testing is shown in Figure 9. The automobile is Japanese market minivan-type passenger car (Honda STEPWGN) of 2000 [cc] displacement volume, and the body color is white. The vehicle height is 1770 [mm] and the vehicle width is 1695 [mm]. The height of the headlamps is 800 [mm]. The space between them is 1350 [mm].

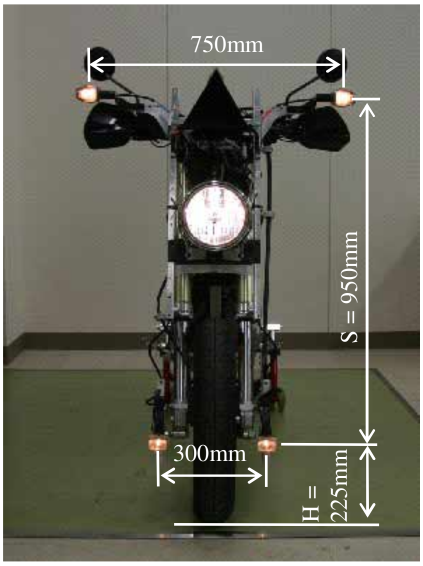

Figure 8. The motorcycle used for the study

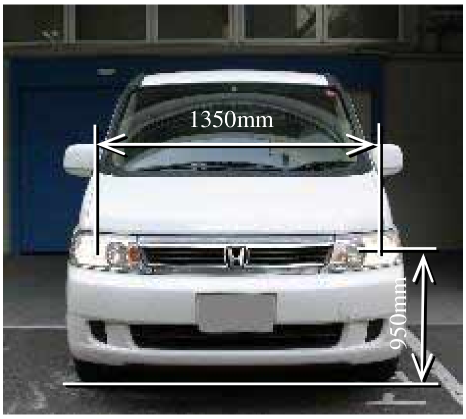

Figure 9. The automobile used for the study

The mean of the CTG ratios of the motorcycle with conventional lighting (MC) and the motorcycle equipped with a LONG lighting system (LONG MC) to an automobile in nighttime is shown in Figure 10. The experimental subjects were 21 people (18 males, 3 females, from 23 years of age to 52 years old) who drive an automobile every day. The range bar on the chart shows the maximum and the minimum measurements for each data set. The luminous intensity of the four lamps of the LONG lighting system was adjusted to 16 [cd], respectively. This intensity is equal to the luminous intensity of the ordinary position lamps for motorcycles. The low-beam headlamps of all the measured stimulus vehicles were switched on. The velocity of the stimulus vehicles was 60 [km/h]. The course used for the evaluation was illuminated by normal overhead road illumination. The illumination was about 6 [lx]. The CTG ratio of the MC to the automobile is 81.9%, and it turns out that the CTG of MC is about 18% smaller than of the automobile. The mean of the automobile's CTG is 4.0 [sec], and the reduction of the CTG is equivalent to 0.72 [sec]. The minimum of the CTG ratio of MC is about 65%, and the reduction of the CTG is equivalent to about 1.4 [sec]. It is shown quantitatively that motorcycles at the same distance and speed as automobiles are perceived being farther away and as traveling at a lower speed than automobiles. On the other hand, the CTG ratio of a LONG MC to the automobile is 98.5%, and it turns out that LONG MC has a sense of speed and distance almost equivalent to an automobile.

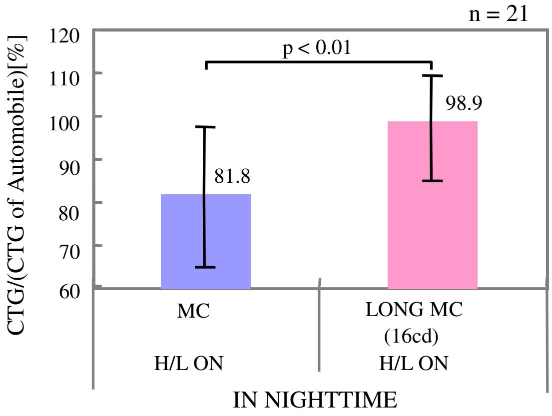

Figure10. Enhanced conspicuity in nighttime

The mean of the CTG ratios of the MC and the LONG MC compared to the automobile in daytime is shown in Figure 11. The experimental subjects were 14 people (12 males, 2 females, from 23 to 52 years old) who drive an automobile every day. The range bar shows the maximum and the minimum measurements for each data set. The MC was measured on the two conditions that the headlamp was turned off (H/L OFF) and the low-beam headlamp was turned on (H/L ON). The headlamp of the LONG MC was turned off. The luminous intensity of the four lamps of the LONG lighting system was adjusted to 121 [cd], respectively. This intensity is the luminous intensity of the ordinary winker lamps for motorcycles. The velocity of all of the measured stimulus vehicles was the same 60 [km/h] as the measurement in nighttime. The sky illumination on the course is from 4410 [lx] to 33500 [lx]. Since this measurement was performed over seven days, the variation of the sky illumination is large. The headlamps of the automobile were switched off. The CTG ratio of MC (H/L OFF) to the automobile was 86.5% and it turns out that the CTG is 13.5% smaller than that of the automobile. It was shown quantitatively that motorcycles at the same distance and speed as automobiles are perceived as being farther away and traveling at a lower speed than the automobiles in the same daytime conditions. The CTG ratio of MC (H/L ON) to the automobile is 93% and it turns out that the CTG of MC (H/L ON) is 7% larger than the CTG of MC (H/L OFF). This shows that turning on the motorcycle's headlamp in daytime enhances the ability to sense both the distance and speed of an approaching motorcycle. But the CTG was 7% smaller than the automobile. Under these conditions it was not possible to compare the results for the motorcycle to an equivalent automobile by only switching on a headlamp. On the other hand, the CTG ratio of the LONG MC to the automobile is 99%, and it turns out that it is almost equivalent to the CTG of the automobile. This shows that the LONG lighting system makes the motorcycle's conspicuity of distance and speed judgment equivalent to an automobile. As reference information, the mean of the automobile's CTG in daytime is 4.0 [sec], and the same subjects' mean of it in nighttime is 4.1 [sec], and these values are almost same.

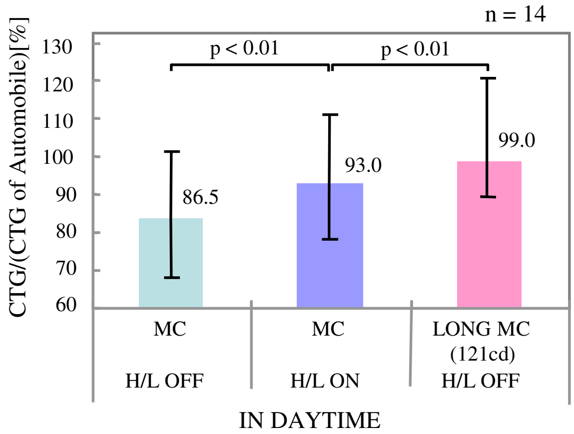

Figure 11. Enhanced conspicuity in daytime

Lamp Layout Dependence

The dependence on the layout of the lamps to enhance conspicuity was measured in nighttime. The longitudinal space between the upper lamps and the lower lamps (S) as well as the height from the ground of the lower lamps (H) were identified as the parameters of the lamps layout. The horizontal space between the two upper lamps was fixed at 750 [mm], and the horizontal space between the two lower lamps was fixed at 300 [mm] (refer to Figure 8). The luminous intensity of four additional lamps of the LONG lighting system were adjusted to 16 [cd], respectively. The low-beam headlamps of all the measured stimulus vehicles were switched on. The velocity of all the measured stimulus vehicles was 60 [km/h]. The course used in the measurements was illuminated by road illumination. The illumination is about 6 [lx]. Figure 12 shows the dependence of the CTG ratio on parameter H. The CTG ratios were measured with the lighting affixed to the motorcycle at three different levels: (125 [mm], 225 [mm], 325 [mm]) of the parameter H. The parameter S is fixed at 950 [mm]. Experimental subjects included 16 people (14 males, 2 females, from 23 to 52 years old) who drive an automobile every day. The error bar shows the full range from maximum to minimum. In the range of parameter H was set in the measurement, it seems that CTG ratio is not dependent on the parameter H. It is expected that the observer's ability to accurately judge distance is enhanced and the CTG ratio increases as parameter H decreases. It seems that additional studies using a range of larger H than 325 [mm] needs to be completed in order to observe the relationship between parameter H and CTG. The mean of CTG of the automobile measured on the same day was 4.0 [sec], and the means of CTG of the motorcycle with LONG lighting system were 3.92 [sec] (H=125 [mm]), 3.94 [sec] (H=225 [mm]) and 3.90 [sec] (H=325 [mm]).

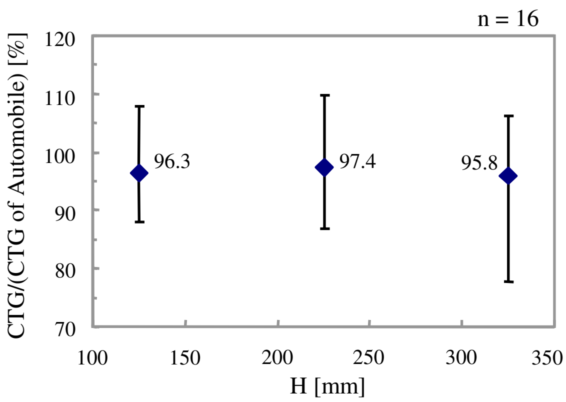

Figure 12. CTG ratio dependence on height (H) of lower lamps in nighttime

Next, the dependence on parameter S of the CTG ratios is shown in Figure13. The CTG ratios were measured at 4 levels (750 [mm], 850 [mm], 950 [mm] and 1050 [mm]) of the parameter S. The parameter H is fixed to 225 [mm]. This experiment included 19 subjects (17 males, 2 females, from 23 to 52 years old) who drive an automobile every day. The error bar shows the maximum and the minimum ranges. It turned out that the CTG ratio increases as parameter S increases when the range of parameter S is between 750 [mm] and 950 [mm]. It is expected that the observer's ability to judge the accuracy of the oncoming motorcycle's distance and speed is enhanced and the CTG ratio increases as parameter S increase. The data from this experiment agrees with this expectation.

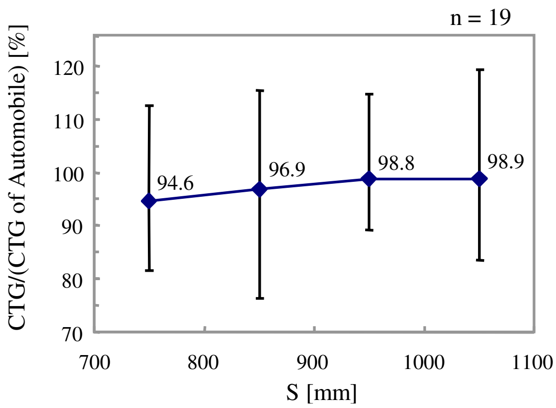

Figure 13. CTG ratio dependence on space (S) between upper lamps and lower lamps in nighttime

As a result of this data, we believe that drivers mainly use the size of the motorcycle's conspicuous parts for to estimate the distance and speed of the approaching vehicle independently in a right-turn across path scenario.

Lamp Luminous Intensity Dependence

The effect of lamp luminous intensity on conspicuity was measured in nighttime. The layout parameters of the lamps are H=225 [mm] and S=950 [mm]. The CTG ratios were measured at three different lamp luminous intensity levels: 16 [cd], 34 [cd] and 50 [cd]. The low-beam headlamps of all the measured stimulus vehicles were switched on. The velocity of each of the measured stimulus vehicles was 60 [km/h]. The course used in the measurements was illuminated by normal road illumination of about 6 [lx]. Experimental subjects included 19 people (17 males, 2 females, from 23 to 52 years old) who drive an automobile every day.

The preliminary experiment showed that stimulus order effect influences the results. In order to minimize the influence of this effect, the ascending series (order of 16 [cd], 34 [cd] and 50 [cd]) and the descending series (order of 50 [cd], 34 [cd] and 16 [cd]) were measured for each experimental subject, and the mean of the values at the same level was adopted as the measure of central tendency at the level. The CTG ratio dependence on lamp luminous intensity in nighttime is shown in Figure 14. It turned out that the CTG ratio increases as the lamp luminous intensity increases. Since a lamp luminous intensity of zero describes a motorcycle without a LONG lighting system, the CTG ratio at zero is estimated at about 81.9 [%], as shown in Figure 10. We expect that the CTG ratio decreases rapidly as the lamp luminous intensity approaches zero in the range smaller than 16 [cd].

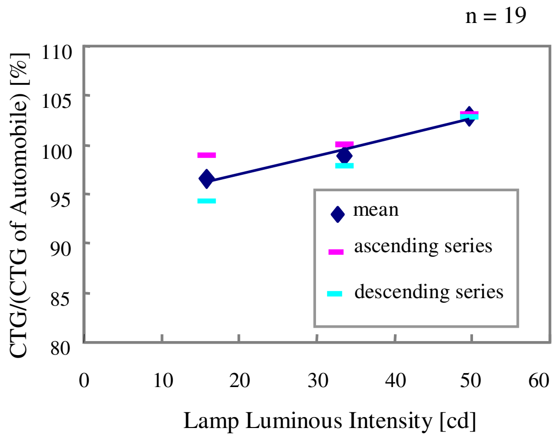

Figure 14. CTG ratio dependence on lamp luminous intensity in nighttime

CONCLUSIONS

The LONG lighting system is proposed as a method of enhancing the conspicuity of motorcycles, specifically to enhance the ability of the driver of an oncoming vehicle to judge distance and speed of a motorcycle to a degree of accuracy equivalent to an automobile.

The enhancement effect of LONG on the judgment of the distance and speed of a motorcycle equipped with the LONG lighting system is evaluated by the CTG ratio measurement, compared to an automobile in similar nighttime and daytime conditions.

In nighttime, it is shown that ordinary motorcycles at the same distance and speed as automobiles may be perceived as being farther away and seem to be traveling at a lower speed than an automobile. The LONG lighting system with the same lamp luminous intensity as conventional motorcycle position lamps makes the motorcycles' conspicuity for an oncoming driver's ability to judge the motorcycle's distance and speed equivalent to that of an automobile.

In daytime, it is shown that motorcycles with unlit headlamps traveling at the same distance and speed as an automobile are perceived as being farther away and traveling at a lower speed than an automobile. The motorcycle's conspicuity related to an oncoming driver's ability to accurately judge the motorcycle's distance and speed does not become equivalent to an automobile, even if the low-beam headlamp is turned on. By adding the LONG lighting system with the same lamp luminous intensity as winkers improves the motorcycle's conspicuity related to the oncoming driver's ability to judge the motorcycle's distance and speed equivalent to that of an automobile.

The effect of the layout of the lamps on conspicuity was measured at night. The results show that the lamp layout has a greater effect on conspicuity as the longitudinal space between the lower lamps and the upper lamps increases within the range of 750 [mm] to 950 [mm].

The effect of lamp luminous intensity on conspicuity was measured at night. This showed that conspicuity was enhanced as the lamp luminous intensity increased.

In order to avoid mad dirt and the breakage by a stone etc., we suppose that the lower lamps of the system are located near the axle of a front wheel. The lamps located in this position vibrate greatly during a run. The problem at the time of applying this technology to a mass-production model is the durability of the lamps to this vibration.

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