

## IMPORTANCE OF CUT-OFF LINE IN AUTOMOTIVE HEADLAMPS AIMING

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### **Abstract**

*The basic element of passing beam headlights is the “cut-off line”. It was intended in European beam pattern as tool for correct adjustment of passing beam according good road illumination distance and oncoming drive eyes protection of excessive glare. Cut-off line was established on the one hand as a natural part separating bright and dark area in the conventional passing beam, on the other assigned its essential function of the visual aiming of headlights. It is used in laboratory practices as well as in vehicles factories and in services and technical periodical inspection. The most important is that cut-off line was defined visually and subjectively over 50 years ago. But needed aiming precision according guaranteed road visibility and glare protection is much higher than historically moulded practical cut-off performance. In paper is analysed definition of cut-off line, their performance and meaning, historical evolution and influence for technical development of headlamps design. Also, mathematical approximation and modelling of cut-off line visual perception is described. The important is analysis of practical examples of real cut-off lines, their connections with significant beam pattern characteristics and possible ambiguous aiming during type approval and during vehicle exploitation. Also, analyzed are perspectives of future cut-off line use, development or - may be replacement by other means better serving this very important task to guarantee correct adjustment beam pattern according good road illumination and protection against excessive glare.*

**Keywords:** *headlights aiming, cut-off line, road illumination, glare protection*

### **1. Introduction**

The basic element of passing beam headlights is the “cut-off line”. It was intended in European beam pattern as tool for correct adjustment of passing beam according far road illumination and protection oncoming drive eyes from excessive glare. Cut-off line was established on the one hand as a natural part separating bright and dark area in the conventional low beam, on the other it was assigned essential function the visual aiming of headlights. It is used as well in test houses practices as in vehicles factories and by service maintenance or periodical technical inspection. The description of cut-of line from many years was very simple and intuitional. It was imperfect and it was reason of ambiguity of aiming as well during type approval as during exploitation. This is especially important because road illumination distance and quality highly depend on initial aiming and aiming tolerances.

### **2. Definitions**

For many years cut-off line definition was as follow:

*“The passing beam must produce a sufficiently sharp cut-off to permit satisfactory adjustment with its aid. The cut-off must be a horizontal straight line on the side opposite to the direction of traffic for which the headlamp is intended” [6].*

It was described shape of it: horizontal on the left side and slant line 15° to the right or angular line 45° degree and then horizontal (Fig. 1).

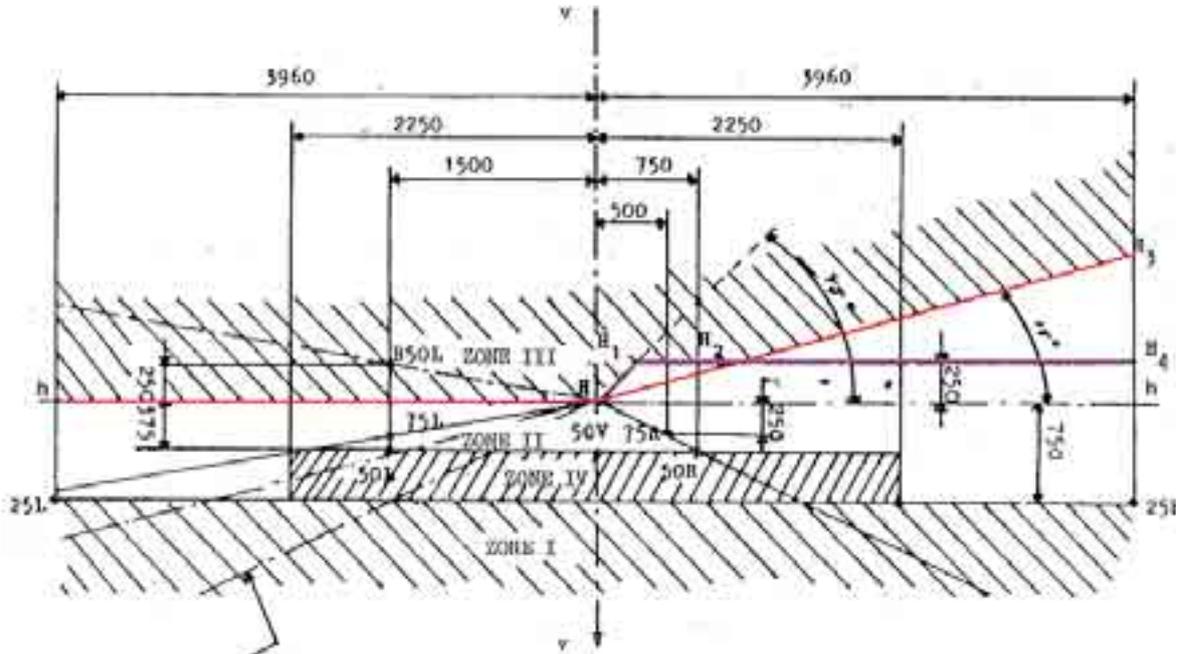


Fig. 1. Primary cut-off shape according UN ECE Regulation No 1 [6]

It was also expected that cut-off would have “elbow” to find correct horizontal position of beam pattern. Above definition is descriptive and question arise how to judge if cut-off is “sufficiently sharp” and what does “satisfactory adjustment” mean. This definition serves from many years but its interpretation can be only visual and subjective. Practically it causes ambiguities when cut-off is assigned by different persons. The cut-off was defined subjectively probably because there was no imagination to do it better that time. Practical aiming using cut-off can cause many doubts as well during type approval test as in exploitation aiming and checking. Such inconvenient situation caused trials do define mathematical models of cut-off. There were considered many proposals of analytical definitions [1-3]. Most of them do not give repeatable results for different headlamps and observers. The best results give methods taking into account logarithmic functions because visual perception of contrast is closer to logarithmic sensitivity than linear. Two of proposed functions give relatively significant number of comparable results: the method of second derivation of logarithm of illumination (E) on vertical angle ( $\beta$ ) [2]:

$$\frac{d(\lg E)}{d\beta} \Big|_{\max} \quad \frac{d^2(\lg E)}{d\beta^2} \Big|_0$$

and ATN empirical method [3]:

$$ATN = 4.91 \cdot \frac{E_2 - E_1}{(E_2 + E_1)^{0.63}},$$

where  $E_1$  and  $E_2$  are illumination on the same vertical line. The cut-off position is the maximum of ATN function

On Fig.2. are presented results of cut-off finding for real headlamp with very sharp and linear cut-off. It is easy to see that independently on formula the shape and position of cut-off is nearly the same.

Finally, in recent years first method was chosen as alternative possibility to visual aiming to use for automatic finding cut-off position [4]. It was introduced as a possibility to automatic finding cut-off position during type approval photometric tests as alternative to visual cut-off finding. For this purpose can be used three vertical scans at  $1.5^\circ$   $2.5^\circ$  and  $3.5^\circ$ .

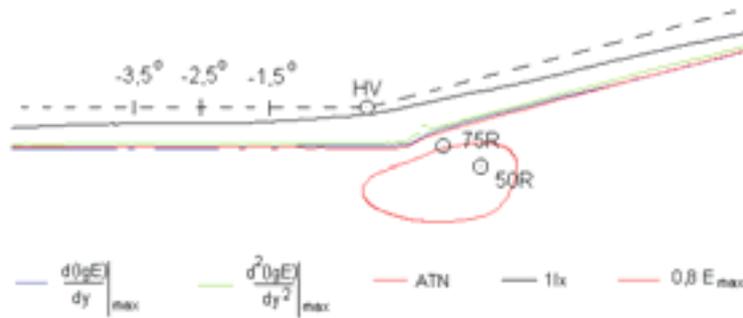


Fig. 2. Mathematical finding cut-off line of real headlamp. Different definitions of cut-off are present. In addition isolux lines 1lx and maximum of illumination

It still problematic how to decide if cut-off shape is correct according prescribed pattern. During visual aiming it is difficult to decide. Three points cut also does not guarantee repeatable results. Some years ago new regulation for adaptive front lighting systems (AFS) was introduced. Also, a new definition of cut-off shape was introduced [4]:

“The “cut-off”, when projected on the aiming screen (...) shall be sufficiently sharp to permit aiming; it shall comply with the following requirements.

1.1. Shape (Fig. 3.)

The “cut-off” shall provide a horizontal “flat part” towards the left, and a raised “shoulder part” to the right; in addition it shall be such, that after being aimed in accordance with the provisions in paragraphs 2.1. to 2.5. below:

- 1.1.1. The “flat part” shall not deviate vertically by more than 0.2 deg up or down from its horizontal median line within 0.5 deg and 4.5 deg left of V-V, and 0.1 deg up or down within two thirds of said length.
- 1.1.2. The raised “shoulder part” shall have a sufficiently defined left edge, and, the line whose origin is at the intersection of line A and the V-V line to be constructed as a tangent to this edge, shall have an inclination versus the line H-H of at least 10 deg and not exceeding 60 deg.”

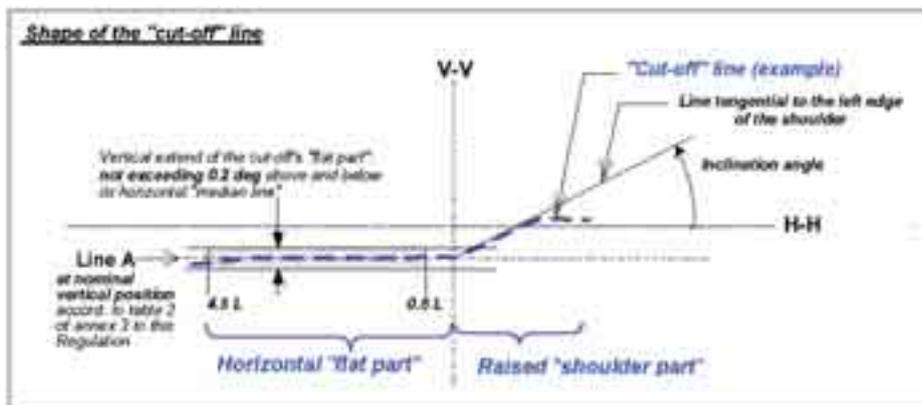


Fig. 3. Intermediate definition of cut-off [4]

There are still not enough precise, subjective descriptions like “sufficiently defined left edge” and “origin” of line, which in prescribed tolerances is ambiguous. Last time was introduced another definition of cut-off [5, 7]:

“The luminous intensity distribution of the principal passing beam headlamp shall incorporate a “cut-off” (Fig. 4.), which enables the headlamp to be adjusted correctly for the photometric measurements and for the aiming on the vehicle. The “cut-off” shall provide:

- (i) A straight “horizontal part” towards the left,
- (ii) A raised “elbow – shoulder” part towards the right.

In each case the “elbow-shoulder” part shall have a sharp edge. For vertical adjustment: the

horizontal part of the "cut-off" is moved upward from below line B and adjusted to its nominal position one per cent (25 cm) below the H-H line;"

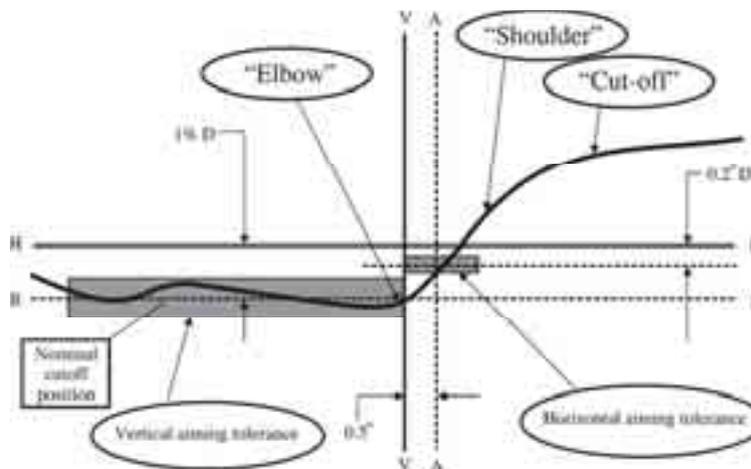


Fig. 4. New way of defining cut-off in UN ECE Regulations [5, 7]

And further:

"For horizontal adjustment: the "elbow-shoulder" part of the "cut-off" shall be moved:

- (a) From right to left and shall be horizontally positioned after its movement so that:
- (i) Above the line  $0.2^\circ D$  its "shoulder" shall not exceed the line A to the left, and
  - (ii) On the line  $0.2^\circ D$  or below its "shoulder" should cross the line A, and
  - (iii) The kink of the "elbow" is basically located within  $\pm 0.5$  degree to the left or right of the V-V line."

Is it also requirement allowing for moving cut-off from its nominal position:

"Where a headlamp so aimed does not meet the requirements (...) its alignment may be changed, provided that the axis of the beam is not displaced:

- Horizontally, from line A by more than:  $0.5^\circ$  to the left or  $0.75^\circ$  to the right,
- Vertically not more than  $0.25^\circ$  up or down from line B."

In fact this complicated definitions and procedures are not simpler to understand and use than older. But attempts to improve definitions shows that problem exist and is not easy to find effective solution. Practically subjectively observed shapes of cut-off's of real headlamps are the base to create definition when most proper way is to clearly define what later should be met. The problem is that real cut-off's are result of headlamp design ideas and possibilities. Finally all presented official definitions are ambiguous as the nature of some groups cut-off creation.

### 3. Practical aspects of use the cut-off

Cut-off described in type approval requirements should serve for correct headlamp positioning during type approval tests. As was shown above there is possible to change cut-off position if photometric results of measurements are outside tolerances. It is allowed change of initial aiming if photometric measurements are not met  $0.25^\circ$  up or down what correspond road illumination distance change from 50 to 135 m for headlamp mounted at height of 750 mm [7]. This is the first step of inconformity between theory and practice added to internal cut-off precision. The other very important function of cut-off is headlamp adjustment on vehicle to obtain optimum road illumination and protect against excessive glare. Firstly it is done during vehicle manufacturing at production lines. For this purpose there are usually used computerised automatic devices equipped with camera. Because of big variety of headlamps and cut-off's such aiming devices are adjusted for given type of headlamp. If is changed the type of mounted headlamp it is need to readjust

device. Sometimes occur unstable conditions because the algorithms used in such devices usually are simple and it is quite difficult to reproduce ambiguous definition in automatic system.

Than aiming is also done during periodical maintenance and after bulb change. This process introduces additional factory and service aiming inaccuracy, which is significantly bigger. To guarantee road visibility and glare protection the aiming tolerances should be narrower than historically moulded practical cut-off performance. Of course many real contemporary headlamps produce very sharp cut-off allowing for aiming precision better than minimum required. In connection with high precision dynamic levelling systems such headlamps can guarantee excellent road illumination during most exploitation condition. But the legal system does not require such precision. Moreover drivers have no additional information from manufacturers or laboratory side that common headlamp can have much worse performance than needed for safe driving by commonly allowed speed at night.

On Fig. 5. are presented examples of visualisation of mathematically transformed beam patterns - derivation of logarithm of illuminance. There are obtained using device to photometrical measurements utilising image analyser and appropriate image processing. It is possible to see qualitative different nature of each example of beam pattern around cut-off. It is possible to see irregularities, “multiply” lines, images of filament etc.

On Fig.6. are examples of cut-of lines found using different criteria presented on Fig. 2. It help to imagine how can differ real cut-off from theoretical shape and how could be its influence for final aiming. Sharp cut-off with linear shape is easy to obtain in ellipsoidal design of headlamp (projection systems). There are quite popular on the market. But also very popular are FF (free form) designs. For this technology shape and sharpness of cut-off strongly depend on design philosophy. This kind of headlamp often produce irregular cut-off’s very sensitive for filament geometry.

Present system of requirements concerning headlamps is far from perfect. It allow for significant inaccuracy of aiming as well during type approval test as well in exploitation conditions. It is result of historical expectations regarding beam pattern performance restricted by design possibilities existing many years ago. Present technology allow to manufacturing quite regular and sharp cut-off’s but it is no legal motivation for manufacturers to do it. From the other side cut-off quality do not guarantee good performance of headlights. There are more or less separate items possible to optimise during headlamp design process.

Exploitation requirements problems are added to inaccuracies caused by very common definitions of type approval photometrical requirements [5-7]. Sharp cut-off with appropriate shape is quite easy to aim. But more irregular shapes especially according new definitions could cause differential aiming in garage conditions.

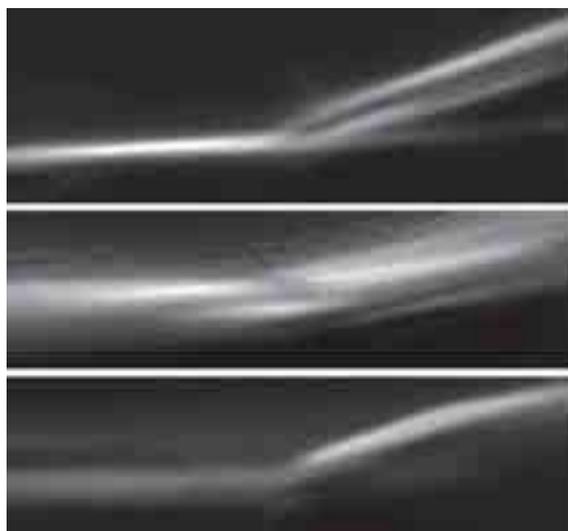


Fig. 5. Visualisation of derivation of logarithm of illuminance for three different beam patterns The brightness areas it is place of cut-off. Measurement done utilising photometrical image analysis

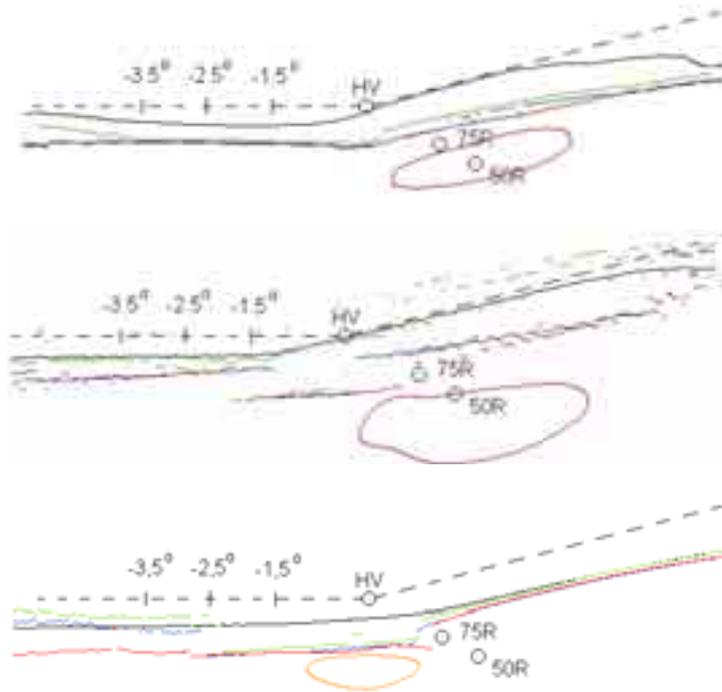


Fig.6. Cut-off for three different beam patterns found using different mathematical criteria. Measurement by use photometrical image analysis

On Fig. 7-9. are shown effects of possible aiming of “double” cut-off.



Fig. 7. Visualisation of derivation of logarithm of illuminance for example of “double” cut-off

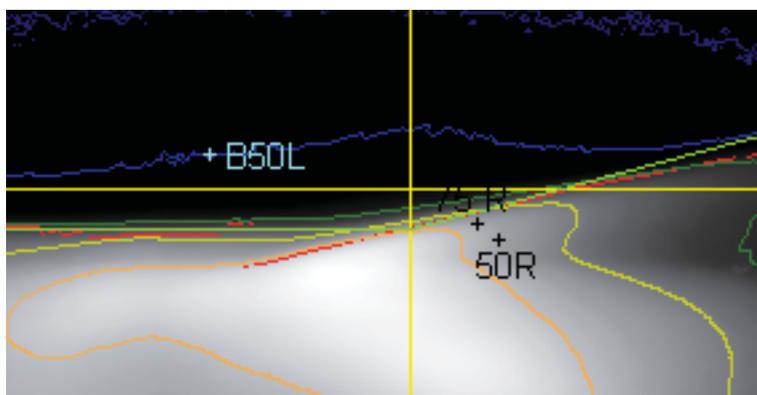


Fig. 8. Aiming by using “higher” most sharp cut-off. Incorrect position of beam pattern – maximum of illumination far from points 50R and 75R

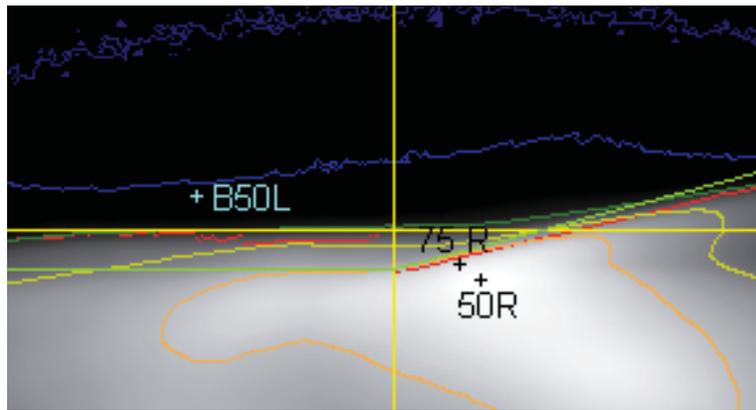


Fig. 9. Aiming by using “lower” not sharp cut-off. Correct position of beam pattern – maximum of illumination close to points 50R and 75R Correct road illumination

The above examples show that in exploitation condition aiming with use cut-off line could result unexpected road illumination and glare.

#### 4. Future

As was shown definitions of cut-off are ambiguous. Also relation of beam pattern to cut-off can be not appropriate. In addition aiming accuracy in exploitation is also not satisfactory.

There are possible two ways of improvement situation. First is to define cut-off requirements more restrictive. It is possible and realistic from technology point of view but some manufacturers could be against such solution. The other is to require other means for aiming than cut-off. There are possible different solutions but the most reasonable looks to be to base aiming on photometric measurements of beam pattern. Such possibility is accessible by use “headlights analyser, innovative diagnostic device using image analysis of whole beam pattern.

#### 5. Conclusions

Cut-off line in passing beam has very important function because serve for headlamp aiming. Present system of requirements concerning headlamps is far from perfect. This caused that precision of defining and checking cut-off performance and aiming is not appropriate to needs. It was historically defined in subjective and descriptive way. Even though changes done in definitions last years the precision of real cut-off line is still insufficient. Moreover it could be doubtful when aiming “old” and “new” headlamps. But it is possible to create sharp distinct cut-off. Nevertheless a lot of them in practical conditions are imperfect and cause problems during type approval test, by vehicle assembly process and during exploitation. From point of view of modern technology and traffic safety cut-off should have much better precision then is presently accepted. It is possible to redefine requirements in more restrictive way but it could cause opposition from manufacturers side. It is also possible to use alternative methods of aiming. The most promising is to measure photometric performance of beam pattern and aim headlamp to maximize range of road illumination and control glare at prescribed and acceptable level. Headlight analyser allow for such quick on field measurements and is very promising device.

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