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DETERMINING OF THE INSTANTANEOUS IRRADIATED AREA OF THE LOWER ABSORBER SURFACE OF THE DOUBLE EXPOSURE FLAT-PLATE SOLAR COLLECTOR

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Abstract:

The term double exposure, flat-plate water solar collector is related to the solar collector which has the ability to absorb solar irradiation from the upper and lower surface of its own absorber. Absorption of solar irradiation, from its lower absorber surface is accomplished using reflecting surface placed below the collector. In comparison with conventional flat-plate solar collector, at analyzed collector, insulation mounted in the lower part of the collector box is replaced by glazing. Because of the exclusion of the insulation, therefore reducing overall collector heat losses, absorber of the same is coated with selective coating on both sides. Described collector is analyzed in order to determine the possibilities of improving its efficiency, in comparison with conventional collector, which among other things depends on size of the irradiated area of the lower absorber surface. This paper presents the mathematical model for determining the irradiated area of the lower absorber surface of the mentioned analyzed collector-reflector system for different possible positions and dimensions of the reflector relative to the collector. The model can be used for numerical optimization of the positions and dimensions of the reflective surface (reflector) relative to the collector. The basis and reason for the future conducting of the numerical analysis, relies *on the fact that it is possible, using reflector, to improve collector efficiency, specifically for examined case for 6.52% (10:00 h), 12.53% (12:00 h) and 30.11% (14:00 h).*

Keywords: Double exposure flat-plate collector, mathematical model, absorbed irradiation.

Rezumat

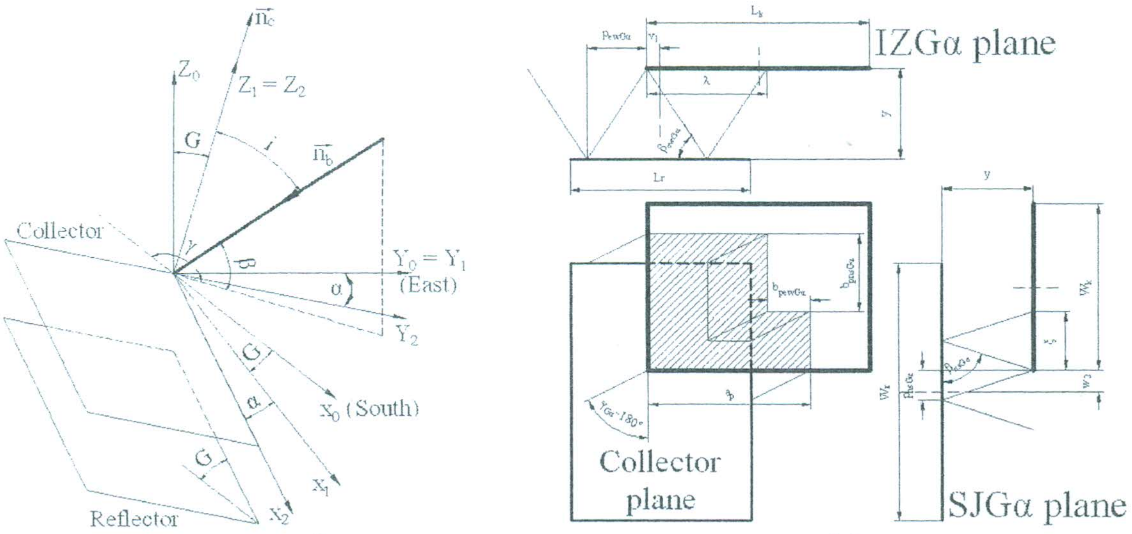
Termenul colector solar cu apă, plat, cu dubla expunere, este legat de termenul colector solar, care are capacitatea de a absorbi radiația solară de la suprafața superioară şi inferioară a absorbantului propriu. Absorbția radiatiei solare de la suprafața inferioară a absorbantului se realizează cu ajutorul unei suprafețe reflectorizante plasate sub colector. În comparație cu colectorul convențional plat, la colectorul analizat, izolarea montata în partea inferioara a cutiei colectorului se înlocuieşte cu o suprafata vitrata. Din cauza excluderii izolației, reducându-se astfel pierderile de caldura in ansamblul colectorului, absorbantul este acoperit cu un strat pe ambele fețe. Colectorul descris este analizat pentru a se determina posibilitățile de îmbunătățire a eficienței sale, în comparație cu colectorul convențional, care, printre altele, depinde de marimea zonei iradiate a suprafeței absorbante inferioare. Această lucrare prezintă modelul matematic pentru stabilirea suprafeței iradiate din partea inferioară a sistemului menționat, si ia in calcul diferite posibile dimensiuni si pozitii a reflectorului în raport cu colectorul. Modelul poate fi folosit pentru optimizarea numerică a pozițiilor şi dimensiunilor suprafeței de reflexie (reflectorului) ir relatie cu colectorul. Bază şi motivul pentru efectuarea analizei numerice in viitor se bazează pe faptul că este posibil, folosind reflectorul, sa se îmbunătățeasca eficiența colectorului, în special pentru cazul examinat, cu 6.52% (10:00 h), 12.53% (12:00 h) şi de 30.11% (14:00 h)

1. Introduction

The need for the increasing usage of the renewable energy sources, specifically in this case, solar energy, requires conducting a different researchs in order to improve the efficiency of the solar systems. The most common systems for absorbing solar energy are flat-plate solar water collectors which by upper surface of its own absorber absorb solar irradiation. This paper points the possible increase of the amount od energy absorbed by the modified collector system called double exposure flat-plate water collector. The term double exposure, flat-plate water solar collector is related to the solar collector which has the ability to absorb solar irradiation from the upper and lower surface of its own absorber. Absorption of solar irradiation, from its lower absorber surface is accomplished using reflecting surface placed below the collector. In comparison with conventional flat-plate solar collector, at analyzed collector, insulation mounted in the lower part of the collector box is replaced by glazing. Because of the exclusion of the insulation, therefore reducing overall collector heat losses, absorber of the same is coated with selective coating on both sides. There are several studies [1,2,3,4,5] relative to this modified collector-reflective system. Within them optimization of the tilt angle of the collector and reflector, without taking into consideration the impact of the position and dimension of the reflector relative to the collector on the system efficiency, is executed. This paper presents the mathematical model for determining the instantaneous irradiated area of the lower absorber surface of the mentioned analyzed collector-reflector system, for different possible positions and dimensions of the reflector relative to the collector, which can be lately used for numerical optimization of the positions and dimensions of the reflector relative to the collector.

2. Mathematical model

The analyzed double exposure flat-plate solar water collector consists of selective absorber and single glazing on its upper and lower side. Reflective surface (hereinafter reflector) is placed below the collector in parallel with the same (Fig. 1). Collector-reflector system (hereinafter CRS) is tilted at angle G relative to horizontal plane, where the collector is fixed while the reflector can be moved in plane parallel to collector plane. The assumption adopted before conducting the analysis is reffered to to the fact that solar beam is specularly reflected.



a) *b)*

Fig. 1. a) Schematic diagram of the analysed CRS with unit vectors of the solar beam and normal of the CRS surface, b) analysed combination of case E1 (in IZGα plane), with condition $L_r < L_k$, $L_r/2 < L_k/2 - v$, $v < L_r/2$, and case B5 (in SJGα plane), with condition $x = (L_k)/2 + w$, $L_r > L_k$, $x < L_r/2 < L_k + w$

The influence of the mutual position of the reflector and collector on absorbed irradiation (collector efficiency) is determined by the size of the irradiated area of the lower absorber surface (A_{ozr}). In order to evaluate the same all CRS is observed in tree planes: plane perpendicular to the CRS plane (IZGα plane) and with view from the south, plane north-south (SJGα plane) and CRS plane. There are different cases of mutual position of the reflector and the collector in both planes for which two parameters „*w*“ i „*v*“, which take into account distance of the reflector's axis from left (right) collector's edge, when looking in plane IZGα, are introduced (Fig. 2). The same cases exist when CRS is projected in SJGα plane, with difference that instead of parameters for reflector and collector lenght *L*, the parameters for their width *W* are used. It is adopted that in IZGα plane, parameters *w*, *v*, *x* are designates with index 1 and in SJGα plane with index 2.

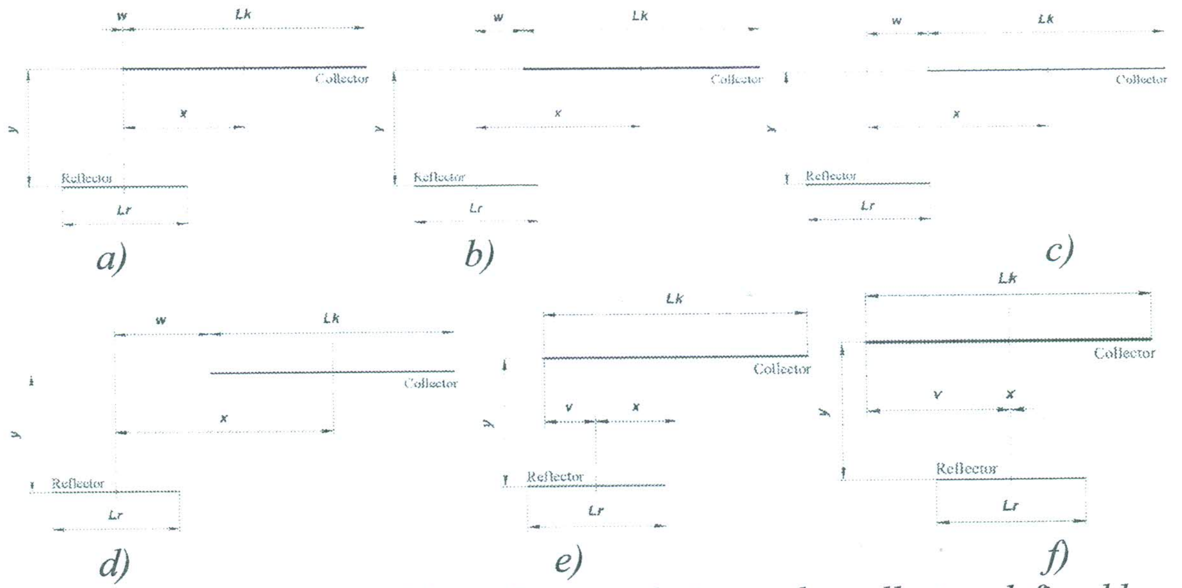


Fig. 2. The position of the reflector relative to the collector defined by parameter w (v): a) $w = 0$ (case A), b) $w < L_r/2$ (B), c) $w = L_r/2$ (C), d) $w > L_r/2$ (D), e) $v < L_k/2$ (E) i f) $v = L_k/2$ (F)

On the displayed figures parameters used in the model are designated and reffered to: w - the distance of the reflector axis measured from the edge of the collector to the exterior (outside) of the same, v - the distance of the reflector axis from the edge of the collector measured to the interior (inside) of the same, x – the distance between reflector and collector axis, y - the distance between the reflector and the collector, Lr - the reflector length and L_k - the collector length. For each of mentioned possible position of reflector relative to collector, defined by the parameters w (4 cases) and v (2 cases), conditions which include different dimensions of reflector lenght and width relative to collector lenght and width, are considered. Accuratelly, condition when $L_r < L_k$, $L_r = L_k$, $L_r > L_k$, for the ratio of the reflector and collector lenght is separately considered as the condition when $W_r < W_k$, $W_r = W_k$, $W_r > W_k$, for ratio of the reflector and collector width. In the relations, beside previously described parameters, lenght parameters as λ, ξ, a_p, $p_{dnsG\alpha}$, $b_{pdnsG\alpha}$, $p_{eewG\alpha}$, $b_{peewG\alpha}$, as well as angle parameters, which define instantaneous sun position, as projection of the solar altitude angle on IZGα plane, $\beta_{ewG\alpha}$, and on SJGα plane, $\beta_{nsG\alpha}$, as well as projection of solar azimuth angle $\gamma_{G\alpha}$ on CRS plane, are also included. The form of the relations for irradiated area of the lower absorber surface depends on whether and how reflected beams form the same area. Because of that, terms like full shading (POS), full irradiation (POZ) and partial irradiation (shading)(DO), are introduced. Full irradiation is situation when solar beams begin to separate from the collector edge or when shadow which collector casts on reflector, does not affect the irradiated area. Otherwise, there is situation called partial irradiation. The term POS points on situation when beams, which falling over the collector edge in one of the planes, affect the forming of irradiated area if and only if the same in other plane fall beside collector edge and reflect on the collector surface. If beams fall over the collector edge in both planes, in that case there is no generation of the mentioned area. For the various situation combinations there are various relations for the instantaneous irradiated area of the lower absorber surface depending on where the same occur whether in IZGα or SJGα plane:

a) $POS_{ewG\alpha}$-$DO_{nsG\alpha}$, $POS_{ewG\alpha}$-$POZ_{nsG\alpha}$, $POS_{nsG\alpha}$-$DO_{ewG\alpha}$, $POS_{nsG\alpha}$-$POZ_{ewG\alpha}$ *i* $POZ_{ewG\alpha}$-$POZ_{nsG\alpha}$

$$A_{ozr} = \xi \cdot \lambda \tag{1.1}$$

b) $DO_{ewG\alpha}$-$DO_{nsG\alpha}$

$$A_{ozr} = \xi \cdot a_p + \lambda \cdot b_{pnsG\alpha} \tag{1.2}$$

c) $POZ_{ewG\alpha}$-$DO_{nsG\alpha}$

$$A_{ozr} = \xi \cdot \lambda + \lambda \cdot b_{pnsG\alpha} \tag{1.3}$$

d) $DO_{ewG\alpha}$-$POZ_{nsG\alpha}$

$$A_{ozr} = \xi \cdot a_p \tag{1.4}$$

Within this analysis equations of parameters (eq. 1.5 – 1.114), that are included in relations for determination of the irradiated area of the lower absorber surface, as well as all possible combinations of mutual position of reflector and collector, when looking in IZGα plane, are displayed below:

E1 - $v < L_k/2$, $L_r < L_k$, $L_r/2 < L_k/2 - v$, $v < L_r/2$,
E2 - $v < L_k/2$, $L_r < L_k$, $L_r/2 < L_k/2 - v$, $v = L_r/2$,
E3 - $v < L_k/2$, $L_r < L_k$, $L_r/2 < L_k/2 - v$, $v > L_r/2$,
E4 - $v < L_k/2$, $L_r < L_k$, $L_r/2 = L_k/2 - v$, $v < L_r/2$,
E5 - $v < L_k/2$, $L_r < L_k$, $L_r/2 = L_k/2 - v$, $v = L_r/2$,
E6 - $v < L_k/2$, $L_r < L_k$, $L_r/2 = L_k/2 - v$, $v > L_r/2$,
E7 - $v < L_k/2$, $L_r < L_k$, $L_r/2 > L_k/2 - v$, $v < L_r/2$,
E8 - $v < L_k/2$, $L_r < L_k$, $L_r/2 > L_k/2 - v$, $v = L_r/2$,
E9 - $v < L_k/2$, $L_r < L_k$, $L_r/2 > L_k/2 - v$, $v > L_r/2$,
E10 - $v < L_k/2$, $L_r = L_k$,

E11a - $v < L_k/2$, $L_r > L_k$, $\underline{L_r/2 + v < L_k}$, $\underline{L_r/2 - v < L_k/2}$, **E11b** - $v < L_k/2$, $L_r > L_k$, $\underline{L_r/2 + v < L_k}$, $\underline{L_r/2 - v \geq L_k/2}$,

E12 - $v < L_k/2$, $L_r > L_k$, $\underline{L_r/2 + v = L_k}$, **E13** - $v < L_k/2$, $L_r > L_k$, $\underline{L_r/2 + v > L_k}$, $\underline{L_r/2 + v < 3L_k/2}$,

E14 - $v < L_k/2$, $L_r > L_k$, $\underline{L_r/2 + v > L_k}$, $\underline{L_r/2 + v = 3L_k/2}$, **E15** - $v < L_k/2$, $L_r > L_k$, $\underline{L_r/2 + v > L_k}$, $\underline{L_r/2 + v > 3L_k/2}$,

B1 - $w > L_r/2$, $L_r < L_k$, **B2** - $w > L_r/2$, $L_r = L_k$,

B3 - $w > L_r/2$, $L_r > L_k$, $\underline{L_r/2 < L_k + w}$, $\underline{L_r/2 < L_k/2 + w}$, **B4** - $w > L_r/2$, $L_r > L_k$, $\underline{L_r/2 < L_k + w}$, $\underline{L_r/2 = L_k/2 + w}$,

B5 - $w > L_r/2$, $L_r > L_k$, $\underline{L_r/2 < L_k + w}$, $\underline{L_r/2 > L_k/2 + w}$, **B6** - $w > L_r/2$, $L_r > L_k$, $\underline{L_r/2 = L_k + w}$, $\underline{L_r/2 > L_k/2 + w}$,

B7 - $w > L_r/2$, $L_r > L_k$, $\underline{L_r/2 > L_k + w}$, $\underline{L_r/2 < 3L_k/2 + w}$, **B8** - $w > L_r/2$, $L_r > L_k$, $\underline{L_r/2 > L_k + w}$, $\underline{L_r/2 = 3L_k/2 + w}$,

B9 - $w > L_r/2$, $L_r > L_k$, $\underline{L_r/2 > L_k + w}$, $\underline{L_r/2 > 3L_k/2 + w}$,

D1 - $w > L_r/2$, $L_r < L_k$, **D2** - $w > L_r/2$, $L_r = L_k$,

D3 - $w > L_r/2$, $L_r > L_k$,

C1 - $w = L_r/2$, $L_r < L_k$, **C2** - $w = L_r/2$, $L_r = L_k$,

C3 - $w = L_r/2$, $L_r > L_k$.

Equations for $\beta_{nsG\alpha}$, $\beta_{ewG\alpha}$, $\gamma_{G\alpha}$

$$\cos\beta_{nsG\alpha} = \frac{\left|\left[\cos\alpha\cdot(\cos G\cdot\cos\beta\cdot\cos\gamma+\sin G\cdot\sin\beta)+\sin\alpha\cdot\cos\beta\cdot\sin\gamma\right]\right|}{\sqrt{\left[\cos\alpha\cdot(\cos G\cdot\cos\beta\cdot\cos\gamma+\sin G\cdot\sin\beta)+\sin\alpha\cdot\cos\beta\cdot\sin\gamma\right]^2+(\sin G\cdot\cos\beta\cdot\cos\gamma-\sin\beta\cdot\cos G)^2}} \tag{1.5}$$

$$\cos\beta_{ewG\alpha} = \frac{\left|\left[\sin\alpha\cdot(\cos G\cdot\cos\beta\cdot\cos\gamma+\sin G\cdot\sin\beta)-\cos\alpha\cdot\cos\beta\cdot\sin\gamma\right]\right|}{\sqrt{\left[\sin\alpha\cdot(\cos G\cdot\cos\beta\cdot\cos\gamma+\sin G\cdot\sin\beta)-\cos\alpha\cdot\cos\beta\cdot\sin\gamma\right]^2+(\sin G\cdot\cos\beta\cdot\cos\gamma-\sin\beta\cdot\cos G)^2}} \tag{1.6}$$

$$\cos\gamma_{G\alpha} = \frac{\left|\cos\alpha\cdot(\cos G\cdot\cos\beta\cdot\cos\gamma+\sin G\cdot\sin\beta)+\sin\alpha\cdot\cos\beta\cdot\sin\gamma\right|}{\sqrt{(\cos\beta\cdot\sin\gamma)^2+(\cos G\cdot\cos\beta\cdot\cos\gamma+\sin G\cdot\sin\beta)^2}} \tag{1.7}$$

Equations for λ (ξ)

E1 (E1=E2=E4=E5) *For* $0^\circ < \gamma_{G\alpha} < 180^\circ$, $tg\beta^*_{ewG\alpha}=y/(L_r/2+v_1)$

$$POS_{ewG\alpha}:\ 90^\circ > \beta_{ewG\alpha} > \beta^*_{ewG\alpha} \Rightarrow \lambda = \frac{L_r}{2}+v_1-\frac{y}{tg\beta_{ewG\alpha}} \tag{1.8}$$

E1 *For* $180^\circ < \gamma_{G\alpha} < 360^\circ$, $tg\beta^{*}_{ewG\alpha}=y/(L_r/2-v_1)$, $tg\beta^{**}_{ewG\alpha}=y/(L_r/2+v_1)$, $tg\beta^{***}_{ewG\alpha}=y/(L_k-v_1-L_r/2)$, $tg\beta^{****}_{ewG\alpha}=y/(L_k-v_1+L_r/2)$

$DO_{ewG\alpha}$: $90° > \beta_{ewG\alpha} \geq \beta^*_{ewG\alpha} \Rightarrow \lambda = \frac{2y}{tg\beta_{ewG\alpha}}$,

$$\beta^*_{ewG\alpha} > \beta_{ewG\alpha} > \beta^{**}_{ewG\alpha} \Rightarrow \lambda = \frac{L_r}{2} - v_1 + \frac{y}{tg\beta_{ewG\alpha}} \quad (1.9)$$

$POZ_{ewG\alpha}$: $\beta^{**}_{ewG\alpha} \geq \beta_{ewG\alpha} \geq \beta^{***}_{ewG\alpha} \Rightarrow \lambda = L_r$,

$$\beta^{***}_{ewG\alpha} > \beta_{ewG\alpha} > \beta^{****}_{ewG\alpha} \Rightarrow \lambda = L_k - v_1 + \frac{L_r}{2} - \frac{y}{tg\beta_{ewG\alpha}} \quad (1.10)$$

E2 *For $180° < \gamma_{G\alpha} < 360°$, $tg\beta^*_{ewG\alpha}=y/L_r$, $tg\beta^{**}_{ewG\alpha}=y/(L_k-v_1-L_r/2)$, $tg\beta^{***}_{ewG\alpha}=y/(L_k-v_1+L_r/2)$*

$$DO_{ewG\alpha}: 90° > \beta_{ewG\alpha} > \beta^*_{ewG\alpha} \Rightarrow \lambda = \frac{y}{tg\beta_{ewG\alpha}} \quad (1.11)$$

$POZ_{ewG\alpha}$: $\beta^*_{ewG\alpha} \geq \beta_{ewG\alpha} \geq \beta^{**}_{ewG\alpha} \Rightarrow \lambda = L_r$,

$$\beta^{**}_{ewG\alpha} > \beta_{ewG\alpha} > \beta^{***}_{ewG\alpha} \Rightarrow \lambda = L_k - v_1 + \frac{L_r}{2} - \frac{y}{tg\beta_{ewG\alpha}} \quad (1.12)$$

E3 (E3=E6) *For $0° < \gamma_{G\alpha} < 180°$, $tg\beta^*_{ewG\alpha}=y/(v_1-Lr/2)$, $tg\beta^{**}_{ewG\alpha}=y/(L_r/2+v_1)$*

$POS_{ewG\alpha}$: $90° > \beta_{ewG\alpha} \geq \beta^*_{ewG\alpha} \Rightarrow \lambda = L_r$,

$$\beta^*_{ewG\alpha} > \beta_{ewG\alpha} > \beta^{**}_{ewG\alpha} \Rightarrow \lambda = \frac{L_r}{2} + v_1 - \frac{y}{tg\beta_{ewG\alpha}} \quad (1.13)$$

E3 *For $180° < \gamma_{G\alpha} < 360°$, $tg\beta^*_{ewG\alpha}=y/(v_1-Lr/2)$, $tg\beta^{**}_{ewG\alpha}=y/(L_r/2+v_1)$, $tg\beta^{***}_{ewG\alpha}=y/(L_k-v_1-L_r/2)$, $tg\beta^{****}_{ewG\alpha}=y/(L_k-v_1+L_r/2)$*

$$POS_{ewG\alpha}: 90° > \beta_{ewG\alpha} \geq \beta^*_{ewG\alpha} \Rightarrow \lambda = L_r \quad (1.14)$$

$$DO_{ewG\alpha}: \beta^*_{ewG\alpha} > \beta_{ewG\alpha} > \beta^{**}_{ewG\alpha} \Rightarrow \lambda = \frac{L_r}{2} - v_1 + \frac{y}{tg\beta_{ewG\alpha}} \quad (1.15)$$

$POZ_{ewG\alpha}$: $\beta^{**}_{ewG\alpha} \geq \beta_{ewG\alpha} \geq \beta^{***}_{ewG\alpha} \Rightarrow \lambda = L_r$,

$$\beta^{***}_{ewG\alpha} > \beta_{ewG\alpha} > \beta^{****}_{ewG\alpha} \Rightarrow \lambda = L_k - v_1 + \frac{L_r}{2} - \frac{y}{tg\beta_{ewG\alpha}} \quad (1.16)$$

E4 (E4=E7) *For $180° < \gamma_{G\alpha} < 360°$, $tg\beta^*_{ewG\alpha}=y/(L_r/2-v_1)$, $tg\beta^{**}_{ewG\alpha}=y/(L_k-v_1-L_r/2)$, $tg\beta^{***}_{ewG\alpha}=y/(L_k-v_1+L_r/2)$*

$DO_{ewG\alpha}$: $90° > \beta_{ewG\alpha} \geq \beta^*_{ewG\alpha} \Rightarrow \lambda = \frac{2y}{tg\beta_{ewG\alpha}}$,

$$\beta^*_{ewG\alpha} > \beta_{ewG\alpha} > \beta^{**}_{ewG\alpha} \Rightarrow \lambda = \frac{L_r}{2} - v_1 + \frac{y}{tg\beta_{ewG\alpha}} \quad (1.17)$$

$POZ_{ewG\alpha}$: $\beta^{**}_{ewG\alpha} \geq \beta_{ewG\alpha} > \beta^{***}_{ewG\alpha} \Rightarrow \lambda = L_k - v_1 + \frac{L_r}{2} - \frac{y}{tg\beta_{ewG\alpha}}$ (1.18)

E5 (E5=E8) *For* $180^\circ < \gamma_{G\alpha} < 360^\circ$, $tg\beta^*_{ewG\alpha}=y/(L_k-v_1-L_r/2)$, $tg\beta^{**}_{ewG\alpha}=y/(L_k-v_1+L_r/2)$

$DO_{ewG\alpha}$: $90^\circ > \beta_{ewG\alpha} > \beta^*_{ewG\alpha} \Rightarrow \lambda = \frac{y}{tg\beta_{ewG\alpha}}$ (1.19)

$POZ_{ewG\alpha}$: $\beta^*_{ewG\alpha} \geq \beta_{ewG\alpha} > \beta^{**}_{ewG\alpha} \Rightarrow \lambda = L_k - v_1 + \frac{L_r}{2} - \frac{y}{tg\beta_{ewG\alpha}}$ (1.20)

E6 (E6=E9) *For* $180^\circ < \gamma_{G\alpha} < 360^\circ$, $tg\beta^*_{ewG\alpha}=y/(v_1-Lr/2)$, $tg\beta^{**}_{ewG\alpha}=y/(L_k-v_1-L_r/2)$, $tg\beta^{***}_{ewG\alpha}=y/(L_k-v_1+L_r/2)$

$POS_{ewG\alpha}$: $90^\circ > \beta_{ewG\alpha} \geq \beta^*_{ewG\alpha} \Rightarrow \lambda = L_r$ (1.21)

$DO_{ewG\alpha}$: $\beta^*_{ewG\alpha} > \beta_{ewG\alpha} > \beta^{**}_{ewG\alpha} \Rightarrow \lambda = \frac{L_r}{2} - v_1 + \frac{y}{tg\beta_{ewG\alpha}}$ (1.22)

$POZ_{ewG\alpha}$: $\beta^{**}_{ewG\alpha} \geq \beta_{ewG\alpha} > \beta^{***}_{ewG\alpha} \Rightarrow \lambda = L_k - v_1 + \frac{L_r}{2} - \frac{y}{tg\beta_{ewG\alpha}}$ (1.23)

E7 (E7=E8=E10=E11a=E11b) *For* $0^\circ < \gamma_{G\alpha} < 180^\circ$, $tg\beta^*_{ewG\alpha}=y/(L_k-v_1-L_r/2)$, $tg\beta^{**}_{ewG\alpha}=y/(L_k/2)$, $tg\beta^{***}_{ewG\alpha}=y/(L_r/2+v_1)$

$POS_{ewG\alpha}$: $90^\circ > \beta_{ewG\alpha} \geq \beta^*_{ewG\alpha} \Rightarrow \lambda = \frac{L_r}{2} + v_1 - \frac{y}{tg\beta_{ewG\alpha}}$ (1.24)

$DO_{ewG\alpha}$: $\beta^*_{ewG\alpha} > \beta_{ewG\alpha} > \beta^{**}_{ewG\alpha} \Rightarrow \lambda = \frac{L_r}{2} - L_k + v_1 + \frac{y}{tg\beta_{ewG\alpha}}$ (1.25)

$POZ_{ewG\alpha}$: $\beta^{**}_{ewG\alpha} \geq \beta_{ewG\alpha} > \beta^{***}_{ewG\alpha} \Rightarrow \lambda = \frac{L_r}{2} + v_1 - \frac{y}{tg\beta_{ewG\alpha}}$ (1.26)

E9 *For* $0^\circ < \gamma_{G\alpha} < 180^\circ$. $tg\beta^*_{ewG\alpha}=y/(v_1-Lr/2)$, $tg\beta^{**}_{ewG\alpha}=y/(L_k-v_1-L_r/2)$, $tg\beta^{***}_{ewG\alpha}=y/(L_k/2)$, $tg\beta^{****}_{ewG\alpha}=y/(L_r/2+v_1)$

$$POS_{ewG\alpha}: \; 90° > \beta_{ewG\alpha} \geq \beta^{*}_{ewG\alpha} \Rightarrow \lambda = L_r \qquad ,$$

$$\beta^{*}_{ewG\alpha} > \beta_{ewG\alpha} \geq \beta^{**}_{ewG\alpha} \Rightarrow \lambda = \frac{L_r}{2} + v_1 - \frac{y}{tg\beta_{ewG\alpha}} \qquad (1.27)$$

$$DO_{ewG\alpha}: \; \beta^{**}_{ewG\alpha} > \beta_{ewG\alpha} > \beta^{***}_{ewG\alpha} \Rightarrow \lambda = \frac{L_r}{2} - L_k + v_1 + \frac{y}{tg\beta_{ewG\alpha}} \qquad (1.28)$$

$$POZ_{ewG\alpha}: \; \beta^{***}_{ewG\alpha} \geq \beta_{ewG\alpha} > \beta^{****}_{ewG\alpha} \Rightarrow \lambda = \frac{L_r}{2} + v_1 - \frac{y}{tg\beta_{ewG\alpha}} \qquad (1.29)$$

E10 (E10=E11a) *For* $180° < \gamma_{G\alpha} < 360°$, $tg\beta^{*}_{ewG\alpha}=y/(L_r/2-v_1)$, $tg\beta^{**}_{ewG\alpha}=y/(L_k/2)$, $tg\beta^{***}_{ewG\alpha}=y/(L_k-v_1+L_r/2)$

$$DO_{ewG\alpha}: \; 90° > \beta_{ewG\alpha} \geq \beta^{*}_{ewG\alpha} \Rightarrow \lambda = \frac{2y}{tg\beta_{ewG\alpha}} \qquad ,$$

$$\beta^{*}_{ewG\alpha} > \beta_{ewG\alpha} > \beta^{**}_{ewG\alpha} \Rightarrow \lambda = \frac{L_r}{2} - v_1 + \frac{y}{tg\beta_{ewG\alpha}} \qquad (1.30)$$

$$POZ_{ewG\alpha}: \; \beta^{**}_{ewG\alpha} \geq \beta_{ewG\alpha} > \beta^{***}_{ewG\alpha} \Rightarrow \lambda = L_k - v_1 + \frac{L_r}{2} - \frac{y}{tg\beta_{ewG\alpha}} \qquad (1.31)$$

E11b (E11b=E12=E13=E14=E15) *For* $180° < \gamma_{G\alpha} < 360°$, $tg\beta^{*}_{ewG\alpha}=y/(L_k/2)$, $tg\beta^{**}_{ewG\alpha}=y/(L_r/2-v_1)$, $tg\beta^{***}_{ewG\alpha}=y/(L_k-v_1+L_r/2)$

$$DO_{ewG\alpha}: \; 90° > \beta_{ewG\alpha} > \beta^{*}_{ewG\alpha} \Rightarrow \lambda = \frac{2y}{tg\beta_{ewG\alpha}} \qquad (1.32)$$

$$POZ_{ewG\alpha}: \; \beta^{*}_{ewG\alpha} \geq \beta_{ewG\alpha} \geq \beta^{**}_{ewG\alpha} \Rightarrow \lambda = L_k \qquad ,$$

$$\beta^{**}_{ewG\alpha} > \beta_{ewG\alpha} > \beta^{***}_{ewG\alpha} \Rightarrow \lambda = L_k - v_1 + \frac{L_r}{2} - \frac{y}{tg\beta_{ewG\alpha}} \qquad (1.33)$$

E12 *For* $0° < \gamma_{G\alpha} < 180°$, $tg\beta^{*}_{ewG\alpha}=y/(L_k/2)$, $tg\beta^{**}_{ewG\alpha}=y/(L_r/2+v_1)$

$$DO_{ewG\alpha}: \; 90° > \beta_{ewG\alpha} > \beta^{*}_{ewG\alpha} \Rightarrow \lambda = \frac{y}{tg\beta_{ewG\alpha}} \qquad (1.34)$$

$$POZ_{ewG\alpha}: \; \beta^{*}_{ewG\alpha} \geq \beta_{ewG\alpha} > \beta^{**}_{ewG\alpha} \Rightarrow \lambda = \frac{L_r}{2} + v_1 - \frac{y}{tg\beta_{ewG\alpha}} \qquad (1.35)$$

E13 *For* $0° < \gamma_{G\alpha} < 180°$, $tg\beta^{*}_{ewG\alpha}=y/(L_r/2+v_1-L_k)$, $tg\beta^{**}_{ewG\alpha}=y/(L_k/2)$, $tg\beta^{***}_{ewG\alpha}=y/(L_r/2+v_1)$

$DO_{ewG\alpha}$: $90° > \beta_{ewG\alpha} \geq \beta^{*}_{ewG\alpha} \Rightarrow \lambda = \dfrac{2y}{tg\beta_{ewG\alpha}}$,

$$\beta^{*}_{ewG\alpha} > \beta_{ewG\alpha} > \beta^{**}_{ewG\alpha} \Rightarrow \lambda = \frac{L_r}{2} + v_1 - L_k + \frac{y}{tg\beta_{ewG\alpha}} \quad (1.36)$$

$POZ_{ewG\alpha}$: $\beta^{**}_{ewG\alpha} \geq \beta_{ewG\alpha} > \beta^{***}_{ewG\alpha} \Rightarrow \lambda = \dfrac{L_r}{2} + v_1 - \dfrac{y}{tg\beta_{ewG\alpha}}$ (1.37)

E14 *For* $0° < \gamma_{G\alpha} < 180°$, $tg\beta^{*}_{ewG\alpha} = y/(L_r/2+v_1-L_k)$, $tg\beta^{**}_{ewG\alpha} = y/(L_r/2+v_1)$

$DO_{ewG\alpha}$: $90° > \beta_{ewG\alpha} > \beta^{*}_{ewG\alpha} \Rightarrow \lambda = \dfrac{2y}{tg\beta_{ewG\alpha}}$ (1.38)

$POZ_{ewG\alpha}$: $\beta^{*}_{ewG\alpha} \geq \beta_{ewG\alpha} > \beta^{**}_{ewG\alpha} \Rightarrow \lambda = \dfrac{L_r}{2} + v_1 - \dfrac{y}{tg\beta_{ewG\alpha}}$ (1.39)

E15 *For* $0° < \gamma_{G\alpha} < 180°$, $tg\beta^{*}_{ewG\alpha} = y/(L_k/2)$, $tg\beta^{**}_{ewG\alpha} = y/(L_r/2+v_1-L_k)$, $tg\beta^{***}_{ewG\alpha} = y/(L_r/2+v_1)$

$DO_{ewG\alpha}$: $90° > \beta_{ewG\alpha} > \beta^{*}_{ewG\alpha} \Rightarrow \lambda = \dfrac{2y}{tg\beta_{ewG\alpha}}$ (1.40)

$POZ_{ewG\alpha}$: $\beta^{*}_{ewG\alpha} \geq \beta_{ewG\alpha} \geq \beta^{**}_{ewG\alpha} \Rightarrow \lambda = L_k$,

$$\beta^{**}_{ewG\alpha} > \beta_{ewG\alpha} > \beta^{***}_{ewG\alpha} \Rightarrow \lambda = \frac{L_r}{2} + v_1 - \frac{y}{tg\beta_{ewG\alpha}} \quad (1.41)$$

B1 (B1=B2=B3=B4) *For* $0° < \gamma_{G\alpha} < 180°$, $tg\beta^{*}_{ewG\alpha} = y/(L_r/2-w_1)$

$POS_{ewG\alpha}$: $90° > \beta_{ewG\alpha} > \beta^{*}_{ewG\alpha} \Rightarrow \lambda = \dfrac{L_r}{2} - w_1 - \dfrac{y}{tg\beta_{ewG\alpha}}$

(1.42)

For $180° < \gamma_{G\alpha} < 360°$, $tg\beta^{*}_{ewG\alpha} = y/(L_r/2-w_1)$, $tg\beta^{**}_{ewG\alpha} = y/(L_r/2+w_1)$, $tg\beta^{***}_{ewG\alpha} = y/(L_k+w_1-L_r/2)$, $tg\beta^{****}_{ewG\alpha} = y/(L_k+w_1+L_r/2)$

$DO_{ewG\alpha}$: $90° > \beta_{ewG\alpha} > \beta^{*}_{ewG\alpha} \Rightarrow \lambda = \dfrac{2y}{tg\beta_{ewG\alpha}}$ (1.43)

$POZ_{ewG\alpha}$: $\beta^{*}_{ewG\alpha} \geq \beta_{ewG\alpha} > \beta^{**}_{ewG\alpha} \Rightarrow \lambda = \dfrac{L_r}{2} - w_1 + \dfrac{y}{tg\beta_{ewG\alpha}}$

(1.44)

$POZ_{ewG\alpha}$: $\beta^{**}_{ewG\alpha} \geq \beta_{ewG\alpha} \geq \beta^{***}_{ewG\alpha} \Rightarrow \lambda = L_r$,

$$\beta^{***}_{ewG\alpha} > \beta_{ewG\alpha} > \beta^{****}_{ewG\alpha} \Rightarrow \lambda = L_k + w_1 + \frac{L_r}{2} - \frac{y}{tg\beta_{ewG\alpha}} \quad (1.45)$$

B2 *For* $180^\circ < \gamma_{G\alpha} < 360^\circ$, $tg\beta^{*}_{ewG\alpha}=y/(L_r/2-w_1)$, $tg\beta^{**}_{ewG\alpha}=y/(L_r/2+w_1)$, $tg\beta^{***}_{ewG\alpha}=y/(L_k+w_1+L_r/2)$

$$DO_{ewG\alpha}:\ 90^\circ > \beta_{ewG\alpha} > \beta^{*}_{ewG\alpha} \Rightarrow \lambda = \frac{2y}{tg\beta_{ewG\alpha}} \quad (1.46)$$

$$POZ_{ewG\alpha}:\ \beta^{*}_{ewG\alpha} \geq \beta_{ewG\alpha} > \beta^{**}_{ewG\alpha} \Rightarrow \lambda = \frac{L_r}{2} - w_1 + \frac{y}{tg\beta_{ewG\alpha}}$$

(1.47)

$$POZ_{ewG\alpha}:\ \beta_{ewG\alpha} = \beta^{**}_{ewG\alpha} \Rightarrow \lambda = L_r \quad ,$$

$$\beta^{**}_{ewG\alpha} > \beta_{ewG\alpha} > \beta^{***}_{ewG\alpha} \Rightarrow \lambda = L_k + w_1 + \frac{L_r}{2} - \frac{y}{tg\beta_{ewG\alpha}} \quad (1.48)$$

B3 *For* $180^\circ < \gamma_{G\alpha} < 360^\circ$, $tg\beta^{*}_{ewG\alpha}=y/(L_r/2-w_1)$, $tg\beta^{**}_{ewG\alpha}=y/(L_k+w_1-L_r/2)$, $tg\beta^{***}_{ewG\alpha}=y/(L_r/2+w_1)$, $tg\beta^{****}_{ewG\alpha}=y/(L_k+w_1+L_r/2)$

$$DO_{ewG\alpha}:\ 90^\circ > \beta_{ewG\alpha} > \beta^{*}_{ewG\alpha} \Rightarrow \lambda = \frac{2y}{tg\beta_{ewG\alpha}} \quad (1.49)$$

$$POZ_{ewG\alpha}:\ \beta^{*}_{ewG\alpha} \geq \beta_{ewG\alpha} > \beta^{**}_{ewG\alpha} \Rightarrow \lambda = \frac{L_r}{2} - w_1 + \frac{y}{tg\beta_{ewG\alpha}}$$

(1.50)

$$POZ_{ewG\alpha}:\ \beta^{**}_{ewG\alpha} \geq \beta_{ewG\alpha} \geq \beta^{***}_{ewG\alpha} \Rightarrow \lambda = L_k ,$$

$$\beta^{***}_{ewG\alpha} > \beta_{ewG\alpha} > \beta^{****}_{ewG\alpha} \Rightarrow \lambda = L_k + w_1 + \frac{L_r}{2} - \frac{y}{tg\beta_{ewG\alpha}} \quad (1.51)$$

B4 (B4=B5=B6=B7=B8=B9) *For* $180^\circ < \gamma_{G\alpha} < 360^\circ$, $tg\beta^{*}_{ewG\alpha}=y/(L_r/2-w_1)$, $tg\beta^{**}_{ewG\alpha}=y/(L_r/2+w_1)$, $tg\beta^{***}_{ewG\alpha}=y/(L_k+w_1+L_r/2)$

$$DO_{ewG\alpha}:\ 90^\circ > \beta_{ewG\alpha} > \beta^{*}_{ewG\alpha} \Rightarrow \lambda = \frac{2y}{tg\beta_{ewG\alpha}} \quad (1.52)$$

$$POZ_{ewG\alpha}:\ \beta^{*}_{ewG\alpha} \geq \beta_{ewG\alpha} \geq \beta^{**}_{ewG\alpha}, \Rightarrow \lambda = L_k ,$$

(1.53)

$$\beta^{**}_{ewG\alpha} > \beta_{ewG\alpha} > \beta^{***}_{ewG\alpha} \Rightarrow \lambda = L_k + w_1 + \frac{L_r}{2} - \frac{y}{tg\beta_{ewG\alpha}}$$

B5 *For* $0^\circ < \gamma_{G\alpha} < 180^\circ$, $tg\beta^{*}_{ewG\alpha}=y/(L_k+w_1-L_r/2)$, $tg\beta^{**}_{ewG\alpha}=y/(L_k/2)$, $tg\beta^{***}_{ewG\alpha}=y/(L_r/2-w_1)$

$$POS_{ewG\alpha}:\ 90^\circ > \beta_{ewG\alpha} \geq \beta^{*}_{ewG\alpha} \Rightarrow \lambda = \frac{L_r}{2} - w_1 - \frac{y}{tg\beta_{ewG\alpha}}$$

(1.54)

$DO_{ewG\alpha}$: $\beta^{*}_{ewG\alpha} > \beta_{ewG\alpha} > \beta^{**}_{ewG\alpha} \Rightarrow \lambda = \frac{L_r}{2} - L_k - w_1 + \frac{y}{tg\beta_{ewG\alpha}}$

(1.55)

$POZ_{ewG\alpha}$: $\beta^{**}_{ewG\alpha} \geq \beta_{ewG\alpha} > \beta^{***}_{ewG\alpha} \Rightarrow \lambda = \frac{L_r}{2} - w_1 - \frac{y}{tg\beta_{ewG\alpha}}$

(1.56)

B6 *For* $0° < \gamma_{G\alpha} < 180°$, $tg\beta^{*}_{ewG\alpha} = y/(L_k/2)$, $tg\beta^{**}_{ewG\alpha} = y/(L_r/2 - w_1)$

$DO_{ewG\alpha}$: $90° > \beta_{ewG\alpha} > \beta^{*}_{ewG\alpha} \Rightarrow \lambda = \frac{y}{tg\beta_{ewG\alpha}}$ (1.57)

$POZ_{ewG\alpha}$: $\beta^{*}_{ewG\alpha} \geq \beta_{ewG\alpha} > \beta^{**}_{ewG\alpha} \Rightarrow \lambda = \frac{L_r}{2} - w_1 - \frac{y}{tg\beta_{ewG\alpha}}$ (1.58)

B7 *For* $0° < \gamma_{G\alpha} < 180°$, $tg\beta^{*}_{ewG\alpha} = y/(L_r/2 - L_k - w_1)$, $tg\beta^{**}_{ewG\alpha} = y/(L_k/2)$, $tg\beta^{***}_{ewG\alpha} = y/(L_r/2 - w_1)$

$DO_{ewG\alpha}$:

$90° > \beta_{ewG\alpha} \geq \beta^{*}_{ewG\alpha} \Rightarrow \lambda = \frac{2y}{tg\beta_{ewG\alpha}}$,

$\beta^{*}_{ewG\alpha} > \beta_{ewG\alpha} > \beta^{**}_{ewG\alpha} \Rightarrow \lambda = \frac{L_r}{2} - L_k - w_1 + \frac{y}{tg\beta_{ewG\alpha}}$ (1.59)

$POZ_{ewG\alpha}$: $\beta^{**}_{ewG\alpha} \geq \beta_{ewG\alpha} > \beta^{***}_{ewG\alpha} \Rightarrow \lambda = \frac{L_r}{2} - w_1 - \frac{y}{tg\beta_{ewG\alpha}}$

(1.60)

B8 *For* $0° < \gamma_{G\alpha} < 180°$, $tg\beta^{*}_{ewG\alpha} = y/(L_r/2 - L_k - w_1)$, $tg\beta^{**}_{ewG\alpha} = y/(L_r/2 - w_1)$

$DO_{ewG\alpha}$: $90° > \beta_{ewG\alpha} > \beta^{*}_{ewG\alpha} \Rightarrow \lambda = \frac{2y}{tg\beta_{ewG\alpha}}$ (1.61)

$POZ_{ewG\alpha}$: $\beta^{*}_{ewG\alpha} \geq \beta_{ewG\alpha} > \beta^{**}_{ewG\alpha} \Rightarrow \lambda = \frac{L_r}{2} - w_1 - \frac{y}{tg\beta_{ewG\alpha}}$

(1.62)

B9 *For* $0° < \gamma_{G\alpha} < 180°$, $tg\beta^{*}_{ewG\alpha} = y/(L_k/2)$, $tg\beta^{**}_{ewG\alpha} = y/(L_r/2 - L_k - w_1)$, $tg\beta^{***}_{ewG\alpha} = y/(L_r/2 - w_1)$

$DO_{ewG\alpha}$: $90° > \beta_{ewG\alpha} > \beta^{*}_{ewG\alpha} \Rightarrow \lambda = \frac{2y}{tg\beta_{ewG\alpha}}$ (1.63)

$POZ_{ewG\alpha}$:

$$\beta^{*}_{ewG\alpha} \geq \beta_{ewG\alpha} \geq \beta^{**}_{ewG\alpha} \Rightarrow \lambda = L_k ,$$

$$\beta^{**}_{ewG\alpha} > \beta_{ewG\alpha} > \beta^{***}_{ewG\alpha} \Rightarrow \lambda = \frac{L_r}{2} - w_1 - \frac{y}{tg\beta_{ewG\alpha}} \qquad (1.64)$$

D1 D1=D2=D3 *For* $0^\circ < \gamma_{G\alpha} < 180^\circ$ ***NOTHING***

D1 *For* $180^\circ < \gamma_{G\alpha} < 360^\circ$, $tg\beta^{*}_{ewG\alpha}=y/w_1$, $tg\beta^{**}_{ewG\alpha}=y/L_r+w_1$, $tg\beta^{***}_{ewG\alpha}=y/L_k+w_1$, $tg\beta^{****}_{ewG\alpha}=y/L_k+L_r+w_1$

$POZ_{ewG\alpha}$:

$$\beta^{*}_{ewG\alpha} > \beta_{ewG\alpha} > \beta^{**}_{ewG\alpha} \Rightarrow \lambda = \frac{y}{tg\beta_{ewG\alpha}} - w_1 , \beta^{**}_{ewG\alpha} \geq \beta_{ewG\alpha} \geq \beta^{***}_{ewG\alpha} \Rightarrow \lambda = L_r \qquad (1.65)$$

$$POZ_{ewG\alpha}: \beta^{***}_{ewG\alpha} > \beta_{ewG\alpha} > \beta^{****}_{ewG\alpha} \Rightarrow \lambda = L_r + L_k + w_1 - \frac{y}{tg\beta_{ewG\alpha}} \qquad (1.66)$$

D2 *For* $180^\circ < \gamma_{G\alpha} < 360^\circ$, $tg\beta^{*}_{ewG\alpha}=y/w_1$, $tg\beta^{**}_{ewG\alpha}=y/L_r+w_1$, $tg\beta^{***}_{ewG\alpha}=y/L_k+L_r+w_1$

$$POZ_{ewG\alpha}: \beta^{*}_{ewG\alpha} > \beta_{ewG\alpha} > \beta^{**}_{ewG\alpha} \Rightarrow \lambda = \frac{y}{tg\beta_{ewG\alpha}} - w_1 , \beta_{ewG\alpha} = \beta^{**}_{ewG\alpha} \Rightarrow \lambda = L_r \qquad (1.67)$$

$$POZ_{ewG\alpha}: \beta^{**}_{ewG\alpha} > \beta_{ewG\alpha} > \beta^{***}_{ewG\alpha} \Rightarrow \lambda = L_r + L_k + w_1 - \frac{y}{tg\beta_{ewG\alpha}} \qquad (1.68)$$

D3 *For* $180^\circ < \gamma_{G\alpha} < 360^\circ$, $tg\beta^{*}_{ewG\alpha}=y/w_1$, $tg\beta^{**}_{ewG\alpha}=y/L_k+w_1$, $tg\beta^{***}_{ewG\alpha}=y/L_r+w_1$, $tg\beta^{****}_{ewG\alpha}=y/L_k+L_r+w_1$

$POZ_{ewG\alpha}$:

$$\beta^{*}_{ewG\alpha} > \beta_{ewG\alpha} > \beta^{**}_{ewG\alpha} \Rightarrow \lambda = \frac{y}{tg\beta_{ewG\alpha}} - w_1 , \beta^{**}_{ewG\alpha} \geq \beta_{ewG\alpha} \geq \beta^{***}_{ewG\alpha} \Rightarrow \lambda = L_k \qquad (1.69)$$

$$POZ_{ewG\alpha}: \beta^{***}_{ewG\alpha} > \beta_{ewG\alpha} > \beta^{****}_{ewG\alpha} \Rightarrow \lambda = L_r + L_k + w_1 - \frac{y}{tg\beta_{ewG\alpha}} \qquad (1.70)$$

C1 C1=C2=C3 *For* $0^\circ < \gamma_{G\alpha} < 180^\circ$ ***NOTHING***

C1 *For* $180^\circ < \gamma_{G\alpha} < 360^\circ$, $tg\beta^{*}_{ewG\alpha}=y/L_r$, $tg\beta^{**}_{ewG\alpha}=y/L_k$, $tg\beta^{***}_{ewG\alpha}=y/L_k+L_r$

$POZ_{ewG\alpha}$:

$$90° > \beta_{ewG\alpha} > \beta^{*}_{ewG\alpha} \Rightarrow \lambda = \frac{y}{tg\beta_{ewG\alpha}}, \beta^{*}_{ewG\alpha} \geq \beta_{ewG\alpha} \geq \beta^{**}_{ewG\alpha} \Rightarrow \lambda = L_r$$

(1.71)

$$POZ_{ewG\alpha}: \; \beta^{**}_{ewG\alpha} > \beta_{ewG\alpha} > \beta^{***}_{ewG\alpha} \Rightarrow \lambda = L_r + L_k - \frac{y}{tg\beta_{ewG\alpha}}$$

(1.72)

***C2** For $180° < \gamma_{G\alpha} < 360°$, $tg\beta^{*}{}_{ewG\alpha}=y/L_r$, $tg\beta^{**}{}_{ewG\alpha}=y/L_k+L_r$*

$$POZ_{ewG\alpha}: \; 90° > \beta_{ewG\alpha} > \beta^{*}_{ewG\alpha} \Rightarrow \lambda = \frac{y}{tg\beta_{ewG\alpha}}, \beta_{ewG\alpha} = \beta^{*}_{ewG\alpha} \Rightarrow \lambda = L_r$$

(1.73)

$$POZ_{ewG\alpha}: \; \beta^{*}_{ewG\alpha} > \beta_{ewG\alpha} > \beta^{**}_{ewG\alpha} \Rightarrow \lambda = L_r + L_k - \frac{y}{tg\beta_{ewG\alpha}}$$

(1.74)

***C3** For $180° < \gamma_{G\alpha} < 360°$, $tg\beta^{*}{}_{ewG\alpha}=y/L_k$, $tg\beta^{**}{}_{ewG\alpha}=y/L_r$, $tg\beta^{***}{}_{ewG\alpha}=y/L_k+L_r$*

$POZ_{ewG\alpha}$:

$$90° > \beta_{ewG\alpha} > \beta^{*}_{ewG\alpha} \Rightarrow \lambda = \frac{y}{tg\beta_{ewG\alpha}}, \beta^{*}_{ewG\alpha} \geq \beta_{ewG\alpha} \geq \beta^{**}_{ewG\alpha} \Rightarrow \lambda = L_k$$

(1.75)

$$POZ_{ewG\alpha}: \; \beta^{**}_{ewG\alpha} > \beta_{ewG\alpha} > \beta^{***}_{ewG\alpha} \Rightarrow \lambda = L_r + L_k - \frac{y}{tg\beta_{ewG\alpha}}$$

(1.76)

Equations for λ for $0° < \gamma_{G\alpha} < 180°$ and $180° < \gamma_{G\alpha} < 360°$ are indentical to equations for ξ for $90° < \gamma_{G\alpha} < 270°$ and $270° < \gamma_{G\alpha} < 90°$ respectively (SJGα plane).

In the case when $\gamma_{G\alpha}=0°$, 360° (180°)$\rightarrow\beta_{ewG\alpha} = 90°$, and $\gamma_{G\alpha}=90°$ (270°)$\rightarrow\beta_{nsG\alpha} = 90°$, irradiated area is determined as $A_{ozr} = \xi\cdot\lambda_0$, $A_{ozr} = \xi_0\cdot\lambda$ respectively, where equations for ξ and λ remain same while equations for λ_0 and ξ_0 differs from case to case (**E1=E2=E4=E5=E7=E8=E10=E11a=E11b=E12** - $\lambda_0 = L_r/2+v_1$, $\xi_0 = W_r/2+v_2$, **E3=E6=E9** - $\lambda_0 = L_r$, $\xi_0 = W_r$, **E13=E14=E15** - $\lambda_0 = L_k$, $\xi_0 = W_k$, **B1=B2=B3=B4=B5=B6** - $\lambda_0 = L_r/2-w_1$, $\xi_0 = W_r/2-w_2$, **B7=B8=B9** - $\lambda_0 = L_k$, $\xi_0 = W_k$).

Equations for $p_{nsG\alpha}$

E1 (E1=E4) *For* $270^\circ < \gamma_{G\alpha} < 90^\circ$, $tg\beta^*_{nsG\alpha}=y/W_r/2-v_2$, $tg\beta^{**}_{nsG\alpha}=y/W_r/2+v_2$

$DO_{nsG\alpha}$:

$$90^\circ > \beta_{nsG\alpha} \geq \beta^*_{nsG\alpha} \Rightarrow p_{nsG\alpha} = \frac{\xi}{2},$$

$$\beta^*_{nsG\alpha} > \beta_{nsG\alpha} > \beta^{**}_{nsG\alpha} \Rightarrow p_{nsG\alpha} = \xi - \frac{W_r}{2} + v_2 \qquad (1.77)$$

E1 (E1=E2=E3=E4=E5=E6) *For* $90^\circ < \gamma_{G\alpha} < 270^\circ$ ***NOTHING***

E2 (E2=E5=E8) *For* $270^\circ < \gamma_{G\alpha} < 90^\circ \rightarrow p_{nsG\alpha} = \xi$

E3 (E3=E6=E9) *For* $270^\circ < \gamma_{G\alpha} < 90^\circ \rightarrow p_{nsG\alpha} = v_2-W_r/2+\xi$

E7 (E7=E10=E11a) *For* $270^\circ < \gamma_{G\alpha} < 90^\circ$, $tg\beta^*_{nsG\alpha}=y/W_r/2-v_2$, $tg\beta^{**}_{nsG\alpha}=y/W_k/2$

$DO_{nsG\alpha}$:

$$90^\circ > \beta_{nsG\alpha} \geq \beta^*_{nsG\alpha} \Rightarrow p_{nsG\alpha} = \frac{\xi}{2},$$

$$\beta^*_{nsG\alpha} > \beta_{nsG\alpha} > \beta^{**}_{nsG\alpha} \Rightarrow p_{nsG\alpha} = \xi - \frac{W_r}{2} + v_2 \qquad (1.78)$$

E7 (E7=E8=E9=E10=E11a=E11b) *For* $90^\circ < \gamma_{G\alpha} < 270^\circ \rightarrow p_{nsG\alpha} = W_k - v_2-W_r/2+\xi$

E11b (E11b=E12=E13=E14=E15) *For* $270^\circ < \gamma_{G\alpha} < 90^\circ \rightarrow p_{nsG\alpha} = \xi/2$

E12 *For* $90^\circ < \gamma_{G\alpha} < 270^\circ \rightarrow p_{nsG\alpha} = \xi$

E13 *For* $90^\circ < \gamma_{G\alpha} < 270^\circ$, $tg\beta^*_{nsG\alpha}=y/(W_r/2+v_2-W_k)$, $tg\beta^{**}_{nsG\alpha}=y/W_k/2$

$DO_{nsG\alpha}$:

$$90^\circ > \beta_{nsG\alpha} \geq \beta^*_{nsG\alpha} \Rightarrow p_{nsG\alpha} = \frac{\xi}{2},$$

$$\beta^*_{nsG\alpha} > \beta_{nsG\alpha} > \beta^{**}_{nsG\alpha} \Rightarrow p_{nsG\alpha} = \xi - \frac{W_r}{2} - v_2 + W_k \qquad (1.79)$$

E14 (E14=E15) *For* $90^\circ < \gamma_{G\alpha} < 270^\circ \rightarrow p_{nsG\alpha} = \xi/2$

B1 (B1=B2=B3=B4=B5=B6=B7=B8=B9) *For* $270^\circ < \gamma_{G\alpha} < 90^\circ \rightarrow p_{nsG\alpha} = \xi/2$

B1 (B1=B2=B3=B4) *For* $90^\circ < \gamma_{G\alpha} < 270^\circ$ ***NOTHING***

B5 *For* $90^\circ < \gamma_{G\alpha} < 270^\circ \rightarrow p_{nsG\alpha} = W_k +w_2-W_r/2+\xi$

B6 *For* $90^\circ < \gamma_{G\alpha} < 270^\circ \rightarrow p_{nsG\alpha} = \xi$

B7 *For* $90^\circ < \gamma_{G\alpha} < 270^\circ$, $tg\beta^*_{nsG\alpha}=y/(W_r/2-W_k-w_2)$, $tg\beta^{**}_{nsG\alpha}=y/W_k/2$

$DO_{nsG\alpha}$:

$$90° > \beta_{nsG\alpha} \geq \beta^*_{nsG\alpha} \Rightarrow p_{nsG\alpha} = \frac{\xi}{2},$$

$$\beta^*_{nsG\alpha} > \beta_{nsG\alpha} > \beta^{**}_{nsG\alpha} \Rightarrow p_{nsG\alpha} = \xi - \frac{W_r}{2} + w_2 + W_k \quad (1.80)$$

B8 (B8= B9) *For* $90° < \gamma_{G\alpha} < 270° \rightarrow p_{nsG\alpha} = \xi/2$

Equations for $p_{ewG\alpha}$ are almost indentical to equations for $p_{nsG\alpha}$, with difference that in that case parameters are defined for IZGα plane and for angle interval of $\gamma_{G\alpha}$, $180° < \gamma_{G\alpha} < 360°$ i $0° < \gamma_{G\alpha} < 180°$.

Equations for a_p ($DO_{ewG\alpha}$-$DO_{nsG\alpha}$)

E1 (E1=E4=E7=E10) *For* $180° < \gamma_{G\alpha} < 270°$ *(for* $270° < \gamma_{G\alpha} < 360° \rightarrow tg(360-\gamma_{G\alpha})$*),* $tg(\gamma_{G\alpha}-180°)^* = (L_r/2-v_1)/p_{nsG\alpha}$, $tg(\gamma_{G\alpha}-180°)^{**} = (L_k - v_1 - Lr/2)/p_{nsG\alpha}$

$$tg(\gamma_{G\alpha} - 180°)^* \leq tg(\gamma_{G\alpha} - 180°) \leq tg(\gamma_{G\alpha} - 180°)^{**} \Rightarrow a_p = L_r \quad (1.81)$$

$$tg(\gamma_{G\alpha} - 180°) < tg(\gamma_{G\alpha} - 180°)^* \Rightarrow a_p = \frac{L_r}{2} + v_1 + tg(\gamma_{G\alpha} - 180°) \cdot p_{nsG\alpha} \quad (1.82)$$

$$tg(\gamma_{G\alpha} - 180°) > tg(\gamma_{G\alpha} - 180°)^{**} \Rightarrow a_p = L_k - v_1 + \frac{L_r}{2} - tg(\gamma_{G\alpha} - 180°) \cdot p_{nsG\alpha} \quad (1.83)$$

E1 (E1=E2=E3=E4=E5=E6) *For* $0° < \gamma_{G\alpha} < 180°$ ***NOTHING*** *(for* $90° < \gamma_{G\alpha} < 180° \rightarrow tg(180°-\gamma_{G\alpha})$*)*

E2 (E2=E3=E5=E6=E8=E9) *For* $180° < \gamma_{G\alpha} < 270°$ *(for* $270° < \gamma_{G\alpha} < 360° \rightarrow tg(360-\gamma_{G\alpha})$*),* $tg(\gamma_{G\alpha}-180°)^* = 0$, $tg(\gamma_{G\alpha}-180°)^{**} = (L_k - v_1 - Lr/2)/p_{nsG\alpha}$

$$tg(\gamma_{G\alpha} - 180°)^* \leq tg(\gamma_{G\alpha} - 180°) \leq tg(\gamma_{G\alpha} - 180°)^{**} \Rightarrow a_p = L_r \quad (1.84)$$

$$tg(\gamma_{G\alpha} - 180°) > tg(\gamma_{G\alpha} - 180°)^{**} \Rightarrow a_p = L_k - v_1 + \frac{L_r}{2} - tg(\gamma_{G\alpha} - 180°) \cdot p_{nsG\alpha} \quad (1.85)$$

E7 (E7=E8=E10=E11a=E11b=E12) *For* $0° < \gamma_{G\alpha} < 90°$ *(for* $90° < \gamma_{G\alpha} < 180° \rightarrow tg(180°-\gamma_{G\alpha})$*)*

$$tg(\gamma_{G\alpha}) \geq tg(\gamma_{G\alpha})^{*}, tg(\gamma_{G\alpha})^{*} = 0 \Rightarrow a_p = \frac{L_r}{2} + v_1 - tg(\gamma_{G\alpha}) \cdot p_{nsG\alpha}$$

(1.86)

***E9** For 0° < $\gamma_{G\alpha}$ < 90° (for 90° < $\gamma_{G\alpha}$ < 180° → tg(180°-$\gamma_{G\alpha}$)), tg($\gamma_{G\alpha}$-180°)*= 0, tg($\gamma_{G\alpha}$-180°)**=(v_1-Lr/2)/$p_{nsG\alpha}$*

$$tg(\gamma_{G\alpha})^{*} \leq tg(\gamma_{G\alpha}) \leq tg(\gamma_{G\alpha})^{**} \Rightarrow a_p = L_r \quad (1.87)$$

$$tg(\gamma_{G\alpha}) > tg(\gamma_{G\alpha})^{**} \Rightarrow a_p = v_1 + \frac{L_r}{2} - tg(\gamma_{G\alpha}) \cdot p_{nsG\alpha} \quad (1.88)$$

***E11a (E11a=E11b)** For 180° < $\gamma_{G\alpha}$ < 270° (for 270° < $\gamma_{G\alpha}$< 360° → tg(360-$\gamma_{G\alpha}$)), tg($\gamma_{G\alpha}$-180°)*=(L_k -v_1-Lr/2)/$p_{nsG\alpha}$, tg($\gamma_{G\alpha}$-180°)**= (L_r/2-v_1)/$p_{nsG\alpha}$*

$$tg(\gamma_{G\alpha} - 180°)^{*} \leq tg(\gamma_{G\alpha} - 180°) \leq tg(\gamma_{G\alpha} - 180°)^{**} \Rightarrow a_p = L_k$$

(1.89)

$$tg(\gamma_{G\alpha} - 180°) < tg(\gamma_{G\alpha} - 180°)^{*} \Rightarrow a_p = \frac{L_r}{2} + v_1 + tg(\gamma_{G\alpha} - 180°) \cdot p_{nsG\alpha}$$

(1.90)

$$tg(\gamma_{G\alpha} - 180°) > tg(\gamma_{G\alpha} - 180°)^{**} \Rightarrow a_p = L_k - v_1 + \frac{L_r}{2} - tg(\gamma_{G\alpha} - 180°) \cdot p_{nsG\alpha}$$

(1.91)

***E12 (E12=E13=E14=E15)** For 180° < $\gamma_{G\alpha}$ < 270° (for 270° < $\gamma_{G\alpha}$ < 360° → tg(360-$\gamma_{G\alpha}$)), tg($\gamma_{G\alpha}$-180°)*= 0, tg($\gamma_{G\alpha}$-180°)**=(L_r/2-v_1)/$p_{nsG\alpha}$*

$$tg(\gamma_{G\alpha} - 180°)^{*} \leq tg(\gamma_{G\alpha} - 180°) \leq tg(\gamma_{G\alpha} - 180°)^{**} \Rightarrow a_p = L_k$$

(1.92)

$$tg(\gamma_{G\alpha} - 180°) > tg(\gamma_{G\alpha} - 180°)^{**} \Rightarrow a_p = L_k - v_1 + \frac{L_r}{2} - tg(\gamma_{G\alpha} - 180°) \cdot p_{nsG\alpha}$$

(1.93)

***E13 (E13=E14=E15)** For 0° < $\gamma_{G\alpha}$ < 90° (for 90° < $\gamma_{G\alpha}$ < 180° → tg(180°-$\gamma_{G\alpha}$)), tg($\gamma_{G\alpha}$-180°)*= 0, tg($\gamma_{G\alpha}$-180°)**=(L_r/2+v_1-L_k)/$p_{nsG\alpha}$*

$$tg(\gamma_{G\alpha})^{*} \leq tg(\gamma_{G\alpha}) \leq tg(\gamma_{G\alpha})^{**} \Rightarrow a_p = L_k \quad (1.94)$$

$$tg(\gamma_{G\alpha}) > tg(\gamma_{G\alpha})^{**} \Rightarrow a_p = v_1 + \frac{L_r}{2} - tg(\gamma_{G\alpha}) \cdot p_{nsG\alpha} \quad (1.95)$$

***B1 (B1=B2)** For 180° < $\gamma_{G\alpha}$ < 270° (for 270° < $\gamma_{G\alpha}$ < 360° → tg(360-$\gamma_{G\alpha}$)), tg($\gamma_{G\alpha}$-180°)*=(L_r/2+w_1)/$p_{nsG\alpha}$, tg($\gamma_{G\alpha}$-180°)**=(L_k+w_1-L_r/2)/$p_{nsG\alpha}$*

$$tg(\gamma_{G\alpha} - 180°)^{*} \leq tg(\gamma_{G\alpha} - 180°) \leq tg(\gamma_{G\alpha} - 180°)^{**} \Rightarrow a_p = L_r$$

(1.96)

$$tg(\gamma_{G\alpha}-180°)<tg(\gamma_{G\alpha}-180°)^{*}\Rightarrow a_p=\frac{L_r}{2}-w_1+tg(\gamma_{G\alpha}-180°)\cdot p_{nsG\alpha} \quad (1.97)$$

$$tg(\gamma_{G\alpha}-180°)>tg(\gamma_{G\alpha}-180°)^{**}\Rightarrow a_p=L_k+w_1+\frac{L_r}{2}-tg(\gamma_{G\alpha}-180°)\cdot p_{nsG\alpha} \quad (1.98)$$

B1 (B1=B2=B3=B4) *For 0° < $\gamma_{G\alpha}$ < 180°* ***NOTHING*** *(for 90° < $\gamma_{G\alpha}$ < 180° → tg(180°-$\gamma_{G\alpha}$))*

B3 (B3=B4=B5) *For 180° < $\gamma_{G\alpha}$ < 270° (for 270° < $\gamma_{G\alpha}$ < 360° → tg(360-$\gamma_{G\alpha}$)), tg($\gamma_{G\alpha}$-180°)*=(L_k+w_1-L_r/2)/$p_{nsG\alpha}$, tg($\gamma_{G\alpha}$-180°)**= (L_r/2+w_1)/$p_{nsG\alpha}$*

$$tg(\gamma_{G\alpha}-180°)^{*}\le tg(\gamma_{G\alpha}-180°)\le tg(\gamma_{G\alpha}-180°)^{**}\Rightarrow a_p=L_k \quad (1.99)$$

$$tg(\gamma_{G\alpha}-180°)<tg(\gamma_{G\alpha}-180°)^{*}\Rightarrow a_p=\frac{L_r}{2}-w_1+tg(\gamma_{G\alpha}-180°)\cdot p_{nsG\alpha} \quad (1.100)$$

$$tg(\gamma_{G\alpha}-180°)>tg(\gamma_{G\alpha}-180°)^{**}\Rightarrow a_p=L_k+w_1+\frac{L_r}{2}-tg(\gamma_{G\alpha}-180°)\cdot p_{nsG\alpha} \quad (1.101)$$

B5 (B5=B6) *For 0° < $\gamma_{G\alpha}$ < 90° (for 90° < $\gamma_{G\alpha}$ < 180° → tg(180°-$\gamma_{G\alpha}$))*

$$tg(\gamma_{G\alpha})\ge tg(\gamma_{G\alpha})^{*},tg(\gamma_{G\alpha})^{*}=0\Rightarrow a_p=\frac{L_r}{2}-w_1-tg(\gamma_{G\alpha})\cdot p_{nsG\alpha} \quad (1.102)$$

B6 (B6=B7=B8=B9) *For 180° < $\gamma_{G\alpha}$ < 270° (for 270° < $\gamma_{G\alpha}$ < 360° → tg(360-$\gamma_{G\alpha}$)), tg($\gamma_{G\alpha}$-180°)*=0, tg($\gamma_{G\alpha}$-180°)**=(L_r/2+w_1)/$p_{nsG\alpha}$*

$$tg(\gamma_{G\alpha}-180°)^{*}\le tg(\gamma_{G\alpha}-180°)\le tg(\gamma_{G\alpha}-180°)^{**}\Rightarrow a_p=L_k \quad (1.103)$$

$$tg(\gamma_{G\alpha}-180°)>tg(\gamma_{G\alpha}-180°)^{**}\Rightarrow a_p=L_k+w_1+\frac{L_r}{2}-tg(\gamma_{G\alpha}-180°)\cdot p_{nsG\alpha} \quad (1.104)$$

B7 (B7=B8=B9) *For 0° < $\gamma_{G\alpha}$ < 90° (for 90° < $\gamma_{G\alpha}$ < 180° → tg(180°-$\gamma_{G\alpha}$)), tg($\gamma_{G\alpha}$-180°)*=0, tg($\gamma_{G\alpha}$-180°)**=(L_r/2-w_1-L_k)/$p_{nsG\alpha}$*

$$tg(\gamma_{G\alpha})^{*}\le tg(\gamma_{G\alpha})\le tg(\gamma_{G\alpha})^{**}\Rightarrow a_p=L_k \quad (1.105)$$

$$tg(\gamma_{G\alpha})>tg(\gamma_{G\alpha})^{**}\Rightarrow a_p=\frac{L_r}{2}-w_1-tg(\gamma_{G\alpha})\cdot p_{nsG\alpha} \quad (1.106)$$

Equations for $b_{pnsG\alpha}$ ($DO_{ewG\alpha}$-$DO_{nsG\alpha}$)
E1 (E1-E15) *For* $270^\circ < \gamma_{G\alpha} < 90^\circ$

$DO_{nsG\alpha}$: $$b_{pnsG\alpha} = \frac{W_r}{2} + v_2 - p_{nsG\alpha},$$

$$2p_{nsG\alpha} + b_{pnsG\alpha} > W_k \Rightarrow b_{pnsG\alpha} = W_k - 2p_{nsG\alpha} \quad (1.107)$$

E1 (E1-E6) *For* $90^\circ < \gamma_{G\alpha} < 270^\circ$ ***NOTHING***
E7 (E7-E15) *For* $90^\circ < \gamma_{G\alpha} < 270^\circ \rightarrow b_{pnsG\alpha} = W_k - 2p_{nsG\alpha}$
B1 (B1-B9) *For* $270^\circ < \gamma_{G\alpha} < 90^\circ$

$DO_{nsG\alpha}$: $$b_{pnsG\alpha} = \frac{W_r}{2} - w_2 - p_{nsG\alpha},$$

$$2p_{nsG\alpha} + b_{pnsG\alpha} > W_k \Rightarrow b_{pnsG\alpha} = W_k - 2p_{nsG\alpha} \quad (1.108)$$

B1 (B1-B4) *For* $90^\circ < \gamma_{G\alpha} < 270^\circ$ ***NOTHING***
B5 (B5-B9) *For* $90^\circ < \gamma_{G\alpha} < 270^\circ \rightarrow b_{pnsG\alpha} = W_k - 2p_{nsG\alpha}$

Equations for a_p, $b_{pewG\alpha}$ ($DO_{ewG\alpha}$-$POZ_{nsG\alpha}$)
E1 (E1-E5) *For* $180^\circ < \gamma_{G\alpha} < 360^\circ$

$DO_{ewG\alpha}$: $$b_{pewG\alpha} = \frac{L_r}{2} + v_1 - p_{ewG\alpha},$$

$$b_{pewG\alpha} + 2p_{ewG\alpha} > L_k \Rightarrow b_{pewG\alpha} = L_k - 2p_{ewG\alpha} \quad (1.109)$$

$DO_{ewG\alpha}$: $$a_p = b_{pewG\alpha} + \lambda, b_{pewG\alpha} + 2p_{ewG\alpha} > L_k \Rightarrow a_p = L_k - 2p_{ewG\alpha} + \lambda \quad (1.110)$$

E1 (E1-E6) *For* $0^\circ < \gamma_{G\alpha} < 180^\circ$ ***NOTHING***
E7 (E7-E15) *For* $0^\circ < \gamma_{G\alpha} < 180^\circ$
$DO_{ewG\alpha}$: $$b_{pewG\alpha} = L_k - 2p_{ewG\alpha}, \ a_p = L_k - 2p_{ewG\alpha} + \lambda \quad (1.111)$$
B1 (B1-B9) *For* $180^\circ < \gamma_{G\alpha} < 360^\circ$

$DO_{ewG\alpha}$: $$b_{pewG\alpha} = \frac{L_r}{2} - w_1 - p_{ewG\alpha},$$

$$2p_{ewG\alpha} + b_{pewG\alpha} > L_k \Rightarrow b_{pewG\alpha} = L_k - 2p_{ewG\alpha} \quad (1.112)$$

$DO_{ewG\alpha}$: $$a_p = b_{pewG\alpha} + \lambda, b_{pewG\alpha} + 2p_{ewG\alpha} > L_k \Rightarrow a_p = L_k - 2p_{ewG\alpha} + \lambda \quad (1.113)$$

B1 (B1-B4) *For* $0^\circ < \gamma_{G\alpha} < 180^\circ$ ***NOTHING***
B5 (B5-B9) *For* $0^\circ < \gamma_{G\alpha} < 180^\circ$
$DO_{ewG\alpha}$: $$b_{pewG\alpha} = L_k - 2p_{ewG\alpha}, \ a_p = L_k - 2p_{ewG\alpha} + \lambda \quad (1.114)$$

3. Conclusion

The described mathematical model allows determining of the instantaneous irradiated area for double exposure flat-plate CRS, for its arbitrary tilt and arbitrary position and dimensions of the reflector relative to collector. Thus, the developed model will be used for numerical determination of the optimal dimensions as well as optimal positions of the reflector relative to collector. The basis and reason for future conducting of that analysis relies on the fact that by reflector it is possible to increase the efficiency of the CRS, specifically in this case for 6.52% (10:00 h), 12.53% (12:00 h) and 30.11% (14:00 h) [6].

References

[1] Souka AF. Double exposure flat-plate collector. Solar Energy 1965;9(3):117–8

[2] Souka AF, Safwat HH. Determination of the optimum orientation for the double exposure flat-plate collector and its reflectors. Solar Energy 1966;10(4):170–4

[3] A. F. Souka, H. H. Safwat, Theoretical evaluation of the performance of a double exposure flat-plate collector using a single reflector. Solar Energy 1969;13(3):347–52

[4] D. C. Larson, Mirror enclosures for double-exposure solar collectors, Solar Energy 1979;23(6):517–24

[5] D. C. Larson, Optimization of flat-plate collector-flat mirror systems, Solar Energy 1980;24(2):203–7

[6] Nikolić N, Lukić N. Mathematical model of absorbed solar irradiation of the double exposure flat-plate solar collector, 41st International congress on heating, refrigerating and air - conditioning, Belgrade, 2010, December 1 - 3, pp. 460-71, ISBN 978-86-81505-55-7