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DEVELOPMENT OF EXPRESS-METHODS FOR DESIGN OF SKI SLOPES ILLUMINATION SISTEMS

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ABSTRACT

The article is devoted to the creation of methods of accelerated lighting design of ski slopes for competitions with a television broadcast.

Keywords: sports lighting, ski track, TV – broadcast, design method, reflected glare

1. INTRODUCTION

Currently, both in Russia and abroad winter sports are actively developing, there are new modern route, competitions of international level with TV broadcasting are held. Thus, there is a demand for high-quality lighting of the ski slopes, which would meet the standards of lighting for high-definition television (HDTV).

If we look on the ski slopes as on objects of the lighting design, then we see that they differ from many other sports facilities by its complex volume structure, in which the surfaces of these slopes are located not only at an angle to the horizon, but also have a complex of shapes with many faces. The reflective properties of the illuminated surface of snow cover with high reflectance (from 60 to 95 % for different snow conditions) are of significant importance [1, 2]. Accounting of the reflected component of the vertical illumination allows significantly reduce the number of lighting devices. In addition, snow has a pronounced mirror effect that can have a blinding effect on athletes. The author's analysis of modern lighting computer programs showed that none of them has full functionality for the calculation of the illuminating of ski slopes. And only the "DIALux" program is applicable there, because it allows calculation of direct and reflected lighting components of inclined planes for which the calculation is made. However, there are several serious limitations for the using of this program. First, it is impossible to build a continuous track of complex shape, and the calculation has to be carried out on a set of flat fragments, what reduces the accuracy of the calculations, because for each fragment they are displayed on a separate sheet. Secondly, "DIALux" does not allow calculate the indicator of blindness – one of the most important indicators of quality in sports lighting – for inclined surfaces. The reflected brilliance is not taken into account. Finally, the calculation for complex scenes with a large number of lighting fixtures is too long to allow anybody to quickly assess the results of the changes, made him (for large tracks it takes tens of minutes). At the same time, the specifics of the calculation of sports lighting is such that to achieve a good uniformity of lighting in several directions, it is necessary to make multiple iterations to change the angle of targeting and types of light distribution of each one of several hundreds of searchlights, so the design process of lighting of one track can take several weeks. In addition to these shortcomings of the software, there is an apparent lack of methodological material for the lighting design of such complex objects. In addition to this disadvantage of the software, there is a clear lack of methodological material for the lighting design of such complex objects. Both in domestic and foreign literature, there are only General recommendations on sports lighting, in which only a few lines are given to ski slopes, and often the features of lighting for television broadcasts are not taken into account. The aim of this work was to develop a method of illumination installations designing for competitions with TV- broadcasting, creating high quality coverage of ski slopes with minimal time spent on design. To achieve this goal, it was necessary to develop a program that takes into account the features of illuminated objects, expanding the capabilities of the designer and serving as the basis for the creation of this technique.

2. THE DESIGN METHOD

When starting to design of lighting systems, you must first determine the requirements for lighting. In our country, departmental standards apply to these objects [3] (the regulation of lighting for filming was carried out in addition before the 1980 Olympics [4]), and in European countries (standard [5]) the relevant recommendations of the ICO are also applied [6]. At the same time, the customer usually prepares a task for the lighting of a particular object together with representatives of the sport Federation and of the organization – performer of filming and broadcasting of competitions.

Next step is the determination of the installation locations of lighting devices. To illuminate the ski slopes, a classic “top-side” lighting scheme typical for many sports facilities is used. Batteries of spotlights are installed on the supports located on both sides of the track. As for the height and pitch of the supports, this parameter is entirely determined by the geometry of the route, by its width and angle of inclination. Minimum height and number of supports are laid in the project, taking into account the high costs of supports and their installation on the mountainous areas. This minimum is limited by the requirements to exclude increased blinding action of spot lights and the need to create a uniform illumination of the snow surface. Based on the width of the ski slope, the maximum angle of elevation of the spotlight, under which its blinding action will be within the permissible limits, determines the height of the support. As a rule, this angle should be no more than 70° from the vertical. The support itself should deviate from the track so that the angle between the vertical and the light flux direction from the battery of the searchlights to the near border of the track would be no less than 30°, otherwise it will not be possible to create the necessary vertical illumination in the zone near the support. Thus, we have a very narrow range of geometric parameters, in which the coordinates of the locations of searchlight batteries installed on the supports should be get. Further, a similar method is determined by the step of the supports – the basis is the maximum angle at which the spotlight can be aimed up or down relative to the plane of the route, i.e., as a rule, the same 70°. The camera targeting lines and the line of view of observers are inclined to horizon, the angles of targeting of the searchlights are not postponed from the vertical, but from the perpendicular to the surface of the track at the installation site of the light device. The pitch of the supports should be such that the light spots from the searchlights on the adjacent supports border each other without dark dips. To create uniform illumination of the track, the step of the supports in the projection onto the track plane should not exceed 1.6 length of the perpendicular lowered from the battery of the searchlights on the track plane. This ratio is subject to specification for each specific route during the lighting calculations. After determination of the geometric parameters of the lighting system, further design is carried out using the lighting calculation program. The main stages of design are listed below:

– Setting the design planes and the reflecting surface;

– Placement of television cameras;

– Selection and placement of light batteries;

– The primary target, the adjustment quantity of searchlights;

– Optimization of the light system parameters.

Optimization is the process of selecting the angles of targeting and light distribution of searchlights to achieve the required parameters, and this item takes the bulk of the design time.

The author offers the corresponding design algorithm, presented in Fig. 1. Further consideration of this algorithm is made on the example of its implementation in the experimental calculation program created by the author.

It has the following features: – Display the scene in the graphical window with navigation;

– Upload to the project graph of the light force of the searchlights in space in *ies*- and *ldt*- formats;

– The table view of the lighting devices used in the scene and their characteristics;

– Setting the coordinates of the cameras in the corresponding table;

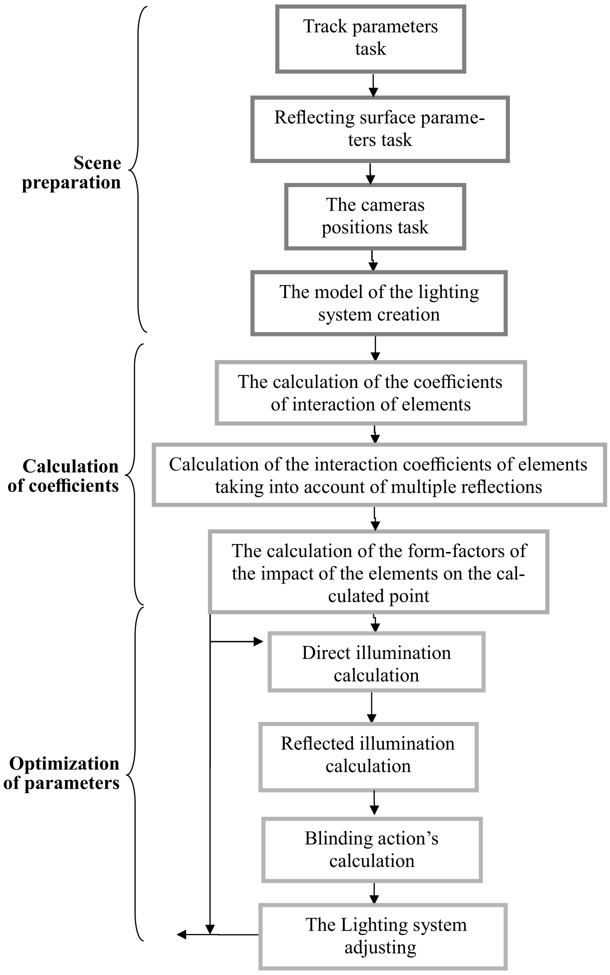

Fig. 1. Algorithm of the ski slopes lighting design

– Calculation of illumination both in the plane of the route and at a given height in the direction of the cameras;

– Calculation of the blinding action on inclined surfaces;

– Display of the calculated values.

3. THE CONSTRUCTION OF THE ROAD AND THE SLOPE

Since the ski track in the plan constitutes a complex polygonal figure, for its construction is used graphic method using the construction plan. This plan, which is given to the developers of the sports track, is the task for the design of engineering systems on the slopes. It shows the route of the isohypsum (lines of equal height), passing there. The user marks on the screen reference points with known heights on the boundaries of the route, using this plan as a substrate. When this process is completed, the program automatically distributes the calculated points for illumination and glare with a given step along the surface of the track (Fig. 2).

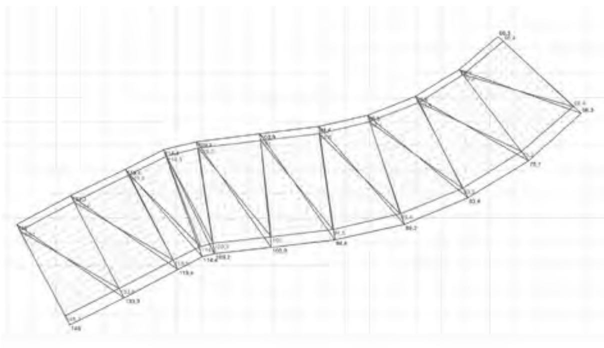

Fig. 2. The route with the calculated points and the surface slope

Similarly, the reflecting surface, which can be larger than the trace, is specified and thereafter it is automatically divided into elementary triangular planes of a given maximum size (Fig. 3).

4. CALCULATION OF THE BLINDING INDICATOR

For installations of outdoor sports lighting and lighting of outdoor the areas of glare are determined in accordance with publication CIE112–1994 [7]. This method has been developed on an extensive experimental basis and has proved its applicability in various lighting systems. Studies have shown that the following two parameters best correlate with the evaluation of glare for outdoor installations:

L_{vl} is the veiling luminance created by the lamps;

L_{ve} is the veiling luminance created by the environment.

The blinding action can be different for different points of the observer's location and for different directions of his gaze. The following formula defines the equivalent veiling luminance L_v (cd / m^2):

$$L_v = 10\sum_{i=1}^{n}(E_{eyei} / \Theta_i^2), \qquad (1)$$

where E_{eyei} is the light intensity of the observer's eye in the plane perpendicular to the line of view created by the *i-th* light source (lx),

Θi is the angle between the line of view of the observer and the direction from the eye to the *i-th* light source, degrees (1.5°<Θi< 60 °),

n is the total number of light sources.

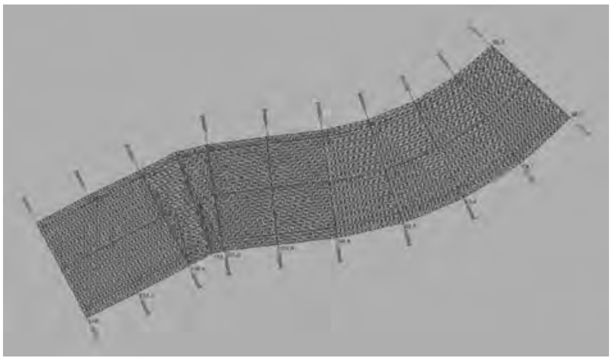

Fig. 3. Slope divided into elements on the background of the substrate

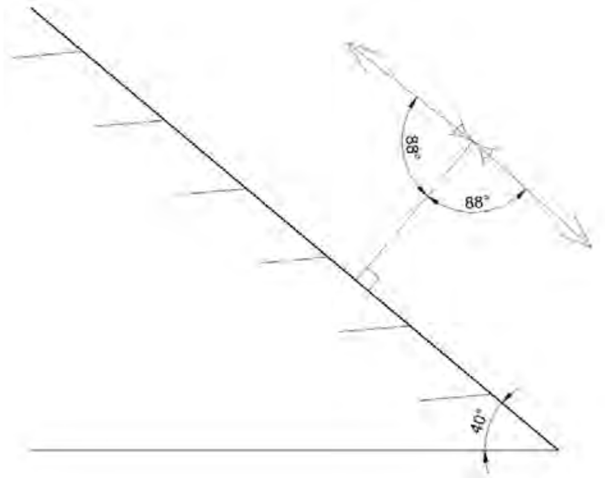

Fig. 4. The directions of the observer's view line on a section inclined of the track

For the L_v calculation, the illuminated area appears illuminated by an infinite number of small light sources. The condition $\Theta > 1{,}5°$ to about L_{vi} automatically will be performed when the observer's gaze direction is no less than 2° from the horizon.

For L_{ve} this limitation means that a part of the illuminated area that falls into the centre of the field of view within the angle of 2×1,5°, will not be taken into account. The value of GR (Glare Rating), characterizing the blinding action, is calculated by the formula:

$$GR = 27 + 24 \cdot \lg(L_{vl} \,/\, L_{ve}^{0,9}). \qquad (2)$$

A lower *GR*-value determines lower glare and better observation conditions.

The calculation of the blinding action is performed at points evenly distributed along the entire track. The step between these points may be less than the step of the points used for the calculation of illumination. Based on the formula (1), an important parameter is the direction of the observer's line of view. At the same time neither domestic, nor foreign standards offer the direction, which need to choose for the sportsmen or the viewer on the ski slope. It is clear that when you look directly at the floodlight battery, the glare index will be unacceptably large even in a properly designed lighting system, so to obtain data useful the direction of the observer's view must be limited. When calculating the planar sports facilities line of view of the observer, height must be limited to an angle of 2 ° down from the horizon, with the position of the eye at a height of 1.5 m from the level of the sports ground. In azimuth covers all directions with a step of 15°.

Returning to the ski slopes, we can be sure that the line of view in most cases will be directed along the track. A mountain skier looks to the track, and viewers, who stand on the same ski slopes, looks to the skier.

In 2013 during the world junior's championship in freestyle in Sochi, the author of this work made a survey of competing athletes on the subject of blinding action during the jump from the springboard in the discipline "ski acrobatics".

The survey of viewers showed that, when the skier approaches to the springboard, he looks practically at his feet, and during the jump, searchlight lighting, made on the upper-side scheme, does not prevent him from concentrating and controlling his actions. Thus, for practical application, you can take a view angle of 2° below the plane of the route, while the rotation of the line of view in azimuth will be in the plane of this section of the route, which can be tilted to the horizon (Fig. 4).

5. THE ALGORITHM OF EXPRESS CALCULATION

The first distinctive feature of the rapid calculation method is the preservation of constant, earlier calculated parameters in the memory and recalculation of the effect on the light distribution only the current changes in the position and targeting of a particular device. The calculation of the direct illuminations of the track and snow is made according to the law of the squares of the distances when the parameters of the spotlights (targeting, location, type, number) are changing. The method is based on the fact that each of the searchlights contributes to the illumination of each calculated point of

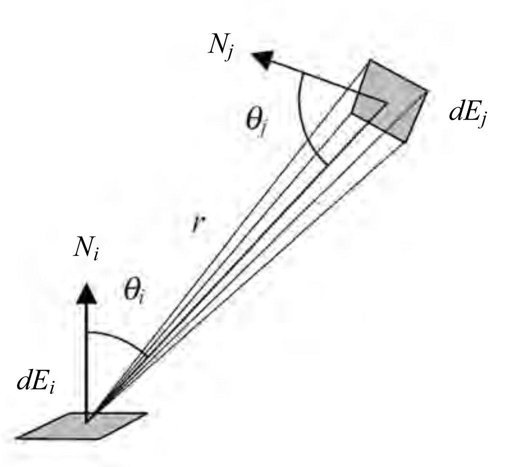

Fig. 5. The geometry of the two elements interaction

the considered slope section. For each searchlight on the considered slope area, this contribution is considered and stored separately. When a searchlight will be replaced with an another one, the previously calculated contribution of the changed searchlight is first deducted from the illumination of each calculated point of the track or snow element, then the light contribution of the new one is calculated and added.

The second idea of saving working time provides that the calculations of the coefficients (form factors) of single and multiple interaction of elements, as well as coefficients that relate the illumination of the calculated points to the illumination of snow elements, are taken from the calculation of the reflected light and are made only once after the creation of the scene geometry. In this regard, the process of rapid calculation can be divided into two main stages: **the initial stage**, at which all coefficients are calculated once and stored in memory **and the optimization stage**, at which the individual light devices are created, removed or changed. Herewith we accept the condition when geometry of the route is constant, it is set once and its change entails the re-conduct of the initial stage of the calculation with the recalculation of all the coefficients. The coefficient of interaction of element *i* with element *j* (Fig. 5) is calculating in accordance with the law of squares of distances:

$$k_{i-j} = \frac{E_j}{E_i} = \frac{\rho \cdot S_i \cos\theta_i \cdot \cos\theta_j}{\pi \cdot r^2}, \quad (3)$$

where: E_i is the illuminance obtained by the element *i* from searchlights,

E_j is the illumination of element *j* as a result of the light reflection from element *i*,

ρ is the reflection coefficient of the element *i*,

S_i is the area of element *i*,

θ_i is the radiation angle of light in the direction of the element *j* with respect to the normal to surface element *i*, θ_j is the angle of incidence of light on the element *j* relative to the normal to its surface,

r is the distance between the centres of the elements.

Similarly, coefficients that relate the illumination of this element of the reflecting surface and this calculated point of the trace are calculated and stored in the memory.

Further, in the process of optimization, the calculated values of snow illumination will be multiplied by the stored coefficients. The coefficients are calculated according to the above formula, where the calculated point on the plane acts instead of the element *j*.

To calculate the coefficients of interaction of elements taking into account multiple reflections in the cycle, the beam passage from one element to an-

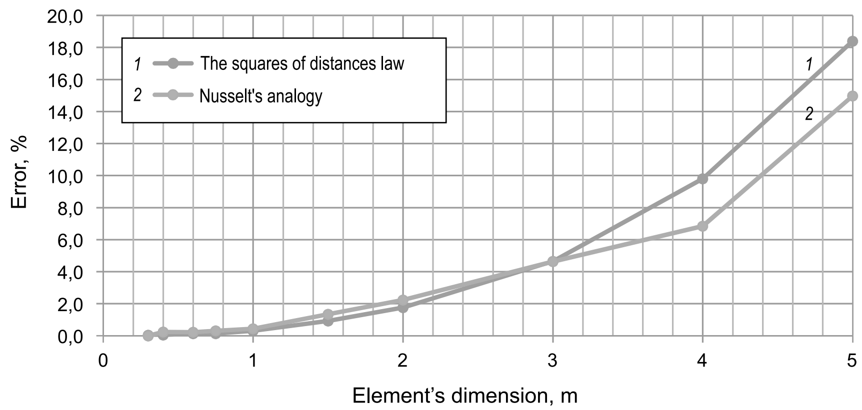

Fig.6. Error dependence on element size

other through all possible options is simulated (for two reflections, the passage through one intermediate element, for three through two intermediate elements, etc.). As a result, the formula for accounting for the contribution to the illumination of the *n-th* iteration looks like

$$E_j = E_i \cdot \sum_{p1,p2,\ldots pn} (k_{i-p1} \cdot k_{p1-p2} \cdot \ldots \cdot k_{pn-j}), \qquad (4)$$

where intermediate elements *p1, p2,… p_n* iterates through all elements of the scene.

The contributions from all iterations taken into account in the calculation must be folded to obtain the final reflected light component of element *j*.

It is known that the law of squared distances gives a significant error when the ratio of the element size to the distance to it is increased. Mathematical modelling made on the basis of the created calculation program showed that for two adjacent triangles the error of calculation of illumination of the centre of mass of one triangle reflected from the centre of mass another triangle light is 60 %, regardless of the angle between them.

Despite the significant error, it should be taken into account that the illumination of the snow element is influenced not only by the adjacent element, but also by many more distant elements, and the direct light from the searchlights creates the main part of the illumination. In addition, the illumination of snow is only an intermediate link in the chain of calculations. To reveal the real influence of this error, it was decided to consider as an alternative the calculation of the interaction coefficients by Nusselts analogy [8], which has an analytically accurate value. The analogy of the Nusselts is that the form factor of a face with respect to a point is a projection of the vector of the solid angle of a face on the calculated plane, which is similar to the projection of a part of the hemisphere of a single radius on the plane of its base. Mathematical modelling with the calculation of vertical illumination on the areas of real tracks showed that the error in the calculation of illumination using the Nusselts analogy becomes significantly lower than the error when the law of squares of distances is used only on large sizes of elements, when the error itself reaches ten percent or more (Fig. 6). At the same time, the calculation of coefficients by the Nusselts analogy takes about twice as much time. Based on this, it is more appropriate to use the law of the squares of distances.

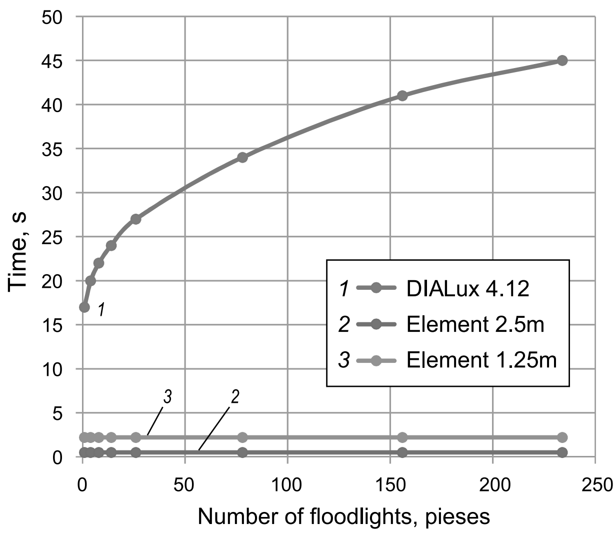

Fig.7. A comparison of the calculation times

Also, a series of calculations with different parameters for two types of tracks was carried out within the framework of the above-described mathematical modelling in the experimental calculation program – a section of the straight line with a break 37° and a section of the half-pipe track, which is a half of the pipe and, therefore, was considered separately. The aim was to determine the maximum size of the elements at which the error does not exceed the specified limits. The following conclusions are drawn from the results: up to the element size of 1.5 m on a straight track and up to 1.25 m on the half-pipe track, the error does not exceed 1 %, with the element size up to 3 m on a straight track and up to 2.5 m on the half-pipe track, the error does not exceed 5 %.

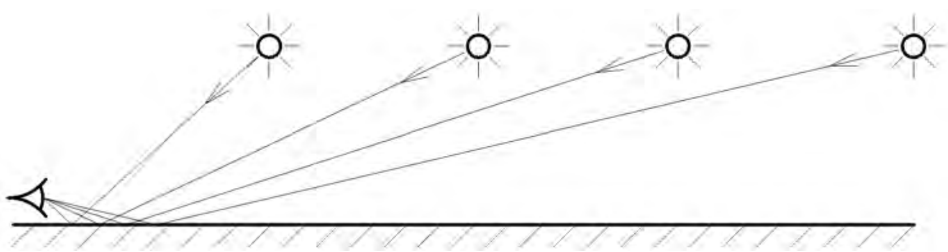

Fig.8. The scheme of the searchlight targeting and moving

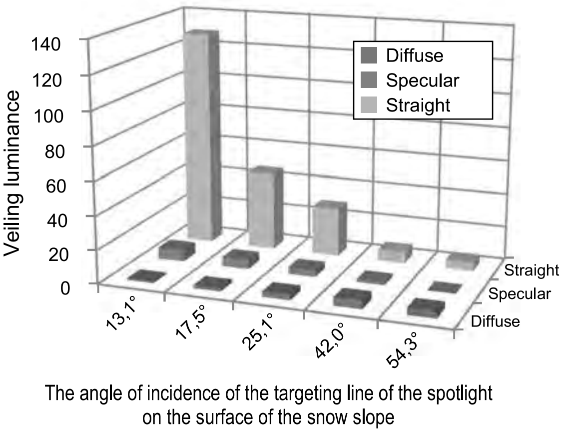

Fig. 9. A comparison of the cover luminance for the searchlights having narrow luminous intensity curve

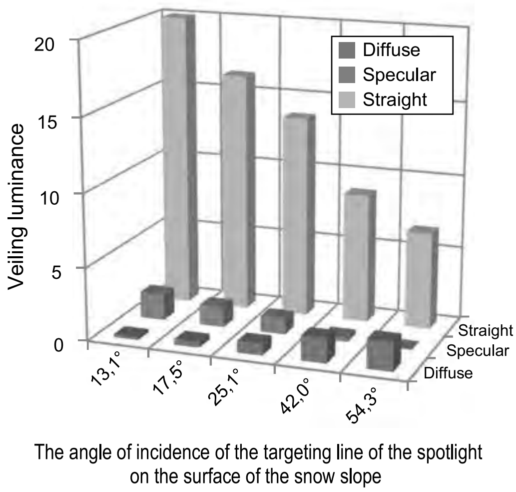

Fig.10. A comparison of the cover luminance for the searchlights having wide luminous intensity curve

Since the rate of coefficients calculation in the proposed method is critically dependent on the number of iterations of multiple reflections taken into account, the next task was to find out the minimum number of iterations that would be sufficient for this type of objects. Using mathematical modelling it was found out that for the section of the half-pipe route, the contribution of the third and further iterations to the vertical illumination does not exceed a tenth of a percent and, accordingly, they cannot be taken into account in the calculation. For a direct plot of the slope of the fracture 37^{o} the contribution of the second and further iterations does not exceed a few tenths of a percent. Also, the contribution of the second iteration in the half-pipe does not exceed 1 %, and the contribution of the first iteration on direct routes – 3 %. Taking into account such small values can be left to the designer's discretion.

6. CONTROL OF THE ACCURACY AND SPEED OF CALCULATION

After the development and implementation of the above algorithm of Express calculation in the experimental calculation program, it was tested for the accuracy of the calculation in two different ways. The first way is the solution of the Sobolev's problem [9], which is a calculation of illumination from a point light source located between two infinite parallel planes, and has an accurate analytical solution. The second way is a comparison with the program "DIALux" on the test section of the track. Comparison of the data obtained in the program of Express-calculation with the analytical solution of the Sobolev's problem and the output data from the program "DIALux" showed good convergence of the results.

In addition, a comparison of the calculation time with the program "DIALux" was made. As already it was mentioned above, for the calculation of sports lighting it is important that the recalculation of the scene after making changes to it is made "in real time", i.e. no more than a few seconds. The comparison was carried out on the test track for two variants of the size of the elements: 1.25 and 2.5 m. For one iteration, the calculation of the coefficients of the interaction were considered as 123 and 25 seconds. The results of the comparison depending on the number of floodlights in the scene is shown in Fig. 7. From the above chart it is clear that, the program of Express calculation allows to calculate the changes several times faster than the program "DIALux" when it optimize the solution and when the settings of only one of all the light devices participating in the scene are changed sequentially.

In this scene, the difference for a single spotlight is 8 to 34 times, depends on the selected element size. With the increase of the number of spotlights, this difference increases many times and ranges from 20 to 90 times.

7. REFLECTED GLARE

Mathematical modelling was carried out on the basis of available literature data on the mirror reflection of snow with ice crust (infusion) [10] in order to assess the blinding effect of the mirror component of snow reflection. A scene with a straight section of the track was created in the program. The observer was located in the middle of the end side of the site, and the spotlight, located on the longitudinal axis of the route, moved along this axis (Fig. 8). The light axis of the spotlight was inclined in a vertical plane passing through the longitudinal axis of the track, so that the reflected beam fell into the eye of the observer, i.e. the worst case from the point of view of blindness was chosen. The observer's view line remained unchanged and was 2° from the horizon accordingly to the existing method of the *GR*-calculation.

It's a pity, but this technique does not allow taking into account the bright distributed spots. Therefore, it was decided to compare veiling luminance for a straight line from the spotlight, diffuse from snow and snow-specula component of illumination in order to assess the effect of reflected glare. The results obtained for the two types of luminous intensity curve are shown in Figs. 9 and 10.

The data obtained clearly demonstrate that the direct component creates a veiling luminance much greater than the specula reflected. Therefore, the contribution of the latter to the blinding effect will not be decisive.

8. CONCLUSION

The method presented in the article allows you to provide qualitative calculations of the ski slopes lighting taking into account the light reflected, while the shape of the track is as close as possible to its real form, and the calculation speed allows display the results within a few seconds. The identified optimal initial data for the calculation, namely the number of multiple reflections and the size of the elements of the partition allow optimize the time spent on the design. The mathematical modelling has shown that the reflected glare from snow is relatively small. In itself, the question of the impact of bright distributed spots on the blinding effect remains open, but the effect of snow reflection can be neglected for practical use in the calculation of ski slopes. The created experimental calculation method has all the necessary functionality for the calculation of ski slopes illumination and, after a small revision, can be used as a full-fledged calculation program.

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