Laser aids to Navigation (Technologies)

by Dr Gennady A Kaloshin, Leading Researcher, Institute of Atmospheric Optics SB RAS, Tomsk and Captain Aleksandr I Gordienko, Head of Department, Principal Department of Navigation and Oceanography, St Petersburg, Russia

The use of lasers as sources of narrow beams of light in beacons considerably increases detectable distances in areas such as in dense atmospheric smoke when traditional lights are not so visible. In this paper results are given of investigations with domestic laser aids to navigation (LANAIDs). Features are considered by comparison and the results of field tests are shown along with the problems of operational use and further development perspectives.

Despite the progress of radionavigation systems the significance of visual aids to navigation in fields of safety and regularity of coastal navigation constantly increases. Moreover, there is an instant necessity to upgrade visual aids to navigation. First of all it concerns the increase of a detection distance and conspicuity of light sources in conditions of low visibility and observation against a complex lighting background and the increase of the operating life and profitability that have to be taken into account.

The laser light sources due to their remarkable properties are widely used in the development of new aids to navigation namely Laser Aids to Navigation (LANAIDs).

The most well known of them are referred to in the publications of the R&D Center of the United States Coast Guard [1,6,7], by Krupp Atlas Elektronik Gmbh [3,4], the Canadian Coast Guard and the Institut National d'Optique [8,9], the Japan Coast Guard [11] and some Russian R&D organisations [2,5,10].

High spectral luminance and monochromaticity make them easily conspicuous and identifiable against background lighting. The small optical beam diameter in combination with high concentration of optical energy allows the creation of a necessary navigating symbol using one position. It is an essential new kind of aid to navigation with scanning of the laser beam in the orientation zone which can be used where the minimum territory is indispensable for the accommodation of aids to navigation, where it is impossible to install a rear range beacon. The small optical diameter and beam divergence greatly decrease a background of multiple scattered radiation, magnifying thereby the limiting detectable distance of luminance, contrast or the LANAID's detection distance.

Concept

Our approach is based on scanning into coverage by the micro radian divergence laser beam, which equals several minutes of arc. It allows an increase of the detection distance by 25 to 30 per cent as contrasted to known solutions and traditional visual aids to navigation. The differences even more increase in low visibility in the atmosphere. In twilight the detection distance is always two or more times greater, than for regular lights at equal

Aides à la navigation laser (Technologies)

Ceci est le second des deux articles écrits par le Dr Gennady A Kaloshin, directeur de recherche de l'Institut d'optique atmosphérique de Tomsk, Russie, et le Commandant Aleksandr I Gordienko, chef de service au sein de l'Administration principale de navigation et d'océanographie à Saint Pétersbourg. Le premier article, «Aides à la navigation laser (méthodes)» est paru dans le numéro 2003/3 du Bulletin de l'AISM.

L'utilisation du laser comme source de rayons lumineux étroits sur les balises accroît considérablement les distances de détection dans des zones où, par exemple, l'atmosphère présente une certaine opacité rendant moins visibles les feux traditionnels. Cet article donne les résultats d'études menées avec des aides à la navigation laser russes (LANAIDs). Il procède à une comparaison des caractéristiques et présente les résultats des essais sur sites, de même que les problèmes d'utilisation et les perspectives de développement futures.

Les auteurs commencent par une introduction au sujet et terminent par une liste de références publiées par la Garde côtière des Etats-Unis, Krupp Atlas Elektronik d'Allemagne, la Garde côtière canadienne, la Garde côtière japonaise, l'Institut National d'Optique de France et quelques organisations russes de recherche et de développement. Leur grande luminosité spectrale et leur mono chromaticité rendent les aides à la navigation laser facilement repérables et identifiables sur les fonds éclairés et le diamètre étroit de leur rayon, combiné à une grande concentration d'énergie optique, permet de créer les symboles de navigation voulus à partir d'une position unique.

L'article met en lumière le concept, les caractéristiques indispensables des sources lumineuses des LANAIDs et leur développement, la technologi du scanner, les résultats obtenus et les problèmes d'application pratique. ◆

power consumption. In the majority of our design solutions the laser beacon is constructed in one position. It is of principal significance that where the minimum territory is indispensable for accommodation and where it is impossible to exhibit or reposition the back range in conditions such as mountainous regions. The narrow laser beams allow by simple and cheap methods the redistribution of a quantity of light power in the laser beam coverage, magnifying thereby detection distance [12-14].

After 80 years the Russian R&D organisations designed the home-produced LANAID models [2, 5, 10], the majority of which should be referred to as laser leading beacons. Their features are given in the Table on page 38.

The indispensable characteristics of LANAIDs' light sources [15]

According to the stated problems and following standard documents the main specifications of lasers, which can be used for laser ranges, are the following: the colour characteristics, output power of radiation and directional diagram **(Fig. 1).**

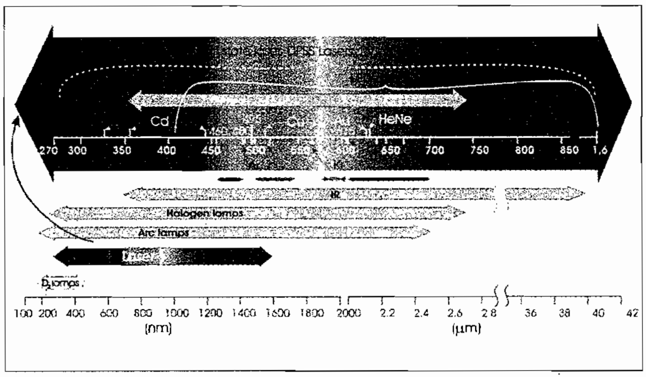

Fig. 1. Available light sources

The colour characteristics of lights should correspond to the following ranges of wavelengths:
red - $\Delta\lambda$ = 615 - 700 nm;
yellow – $\Delta\lambda$ = 585 - 595 nm;
green - $\Delta\lambda$ = 495 - 545 nm;
blue $\Delta\lambda$ = 460 - 480 nm.

An attempt to increase the detection distance especially in conditions of low visibility in the atmosphere when meeting norms of laser safety, assumes that the range of output power depending on the required detection distance can vary within the limits from 4 milliwatt up to 1 watt, and the divergence of radiation - from $6 \cdot 10^{-4}$ up to $3 \cdot 10^{-3}$ rad.

Other characteristics are also important:

- stability of output power of radiation, which should be much less than fluctuations of intensity in the turbulent atmosphere and should not exceed 5 - 7 % during eight hours of operation;
- stability of an axis of a directional diagram should be $(3 - 5) \cdot 10^{-5}$ rad at the requirements to an accuracy of sector borders in limits $\pm 3 \cdot 10^{-4}$ rad at a level 3σ;
- guaranteed time limit (time between failures) should correspond, at least, to seasonal duration of navigation in a near-shore area and is not less than 5000 hours;
- mode of operation is continuous, at impulse - periodic the high frequency of recurrence of impulses is indispensable within the limits of 50 - 100 kHz depending on decided tasks.

Other important operational parameters of light sources in LANAIDs should be minimal whenever possible, among them:

- cost, which is usually in most similar devices equal to half or one third of the cost of the LANAID;
- weight and dimensions;
- turn on time, after which the output parameters are guaranteed;
- recurrence of LANAIDs' parameters at replacement of lasers;
- stability to mechanical effects, to effects of electrostatic fields etc.

Besides the above, parameters should be ensured at changes of the environment: temperature, moisture and aggressive effects.

Among the extremely broad range of existing laser sources, the most attractive for application in visual aids to navigation are the following non-conventional sources: laser diodes and diode-pumped solid-state laser. Also in a number of cases the application in LANAIDs classic He-Ne and solid-state lasers with improved parameters is possible.

During further development of works and understanding of problems, which could be resolved by LANAIDs, two- and one-position laser leading beacons were created.

Scanning technology

Another important component of the laser leading beacon is the scanning device of the laser beam. We use electro-mechanical scanners. The exterior view of this scanner is shown in **Fig. 2.**

The features of the given scanners are as follows:

- resonant frequency, Hz - 1000;
- optical scan angle, degrees optical ±15°;
- mirror reflectivity (AlSiO) - 86%.

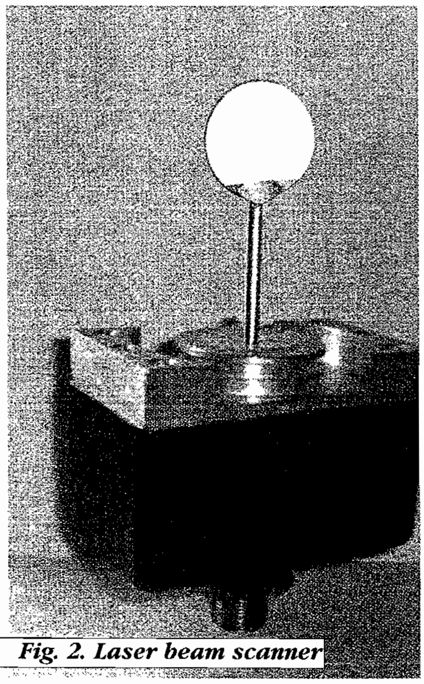

Fig. 2. Laser beam scanner

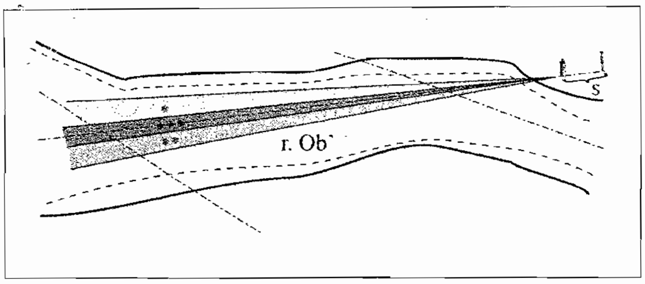

Fig. 3. Nizhneudinskii laser leading beacon

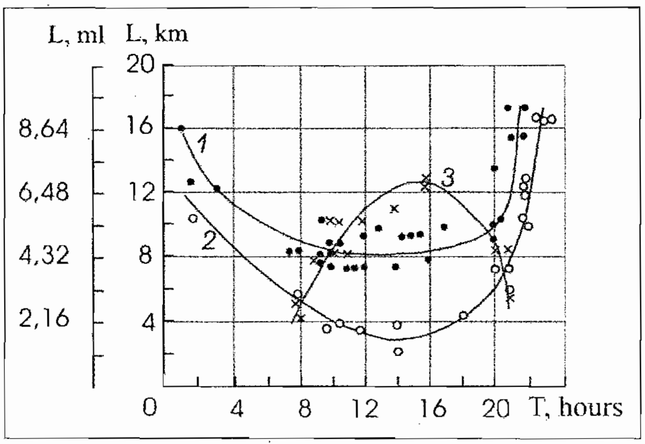

Fig. 4. : (unaided eye)

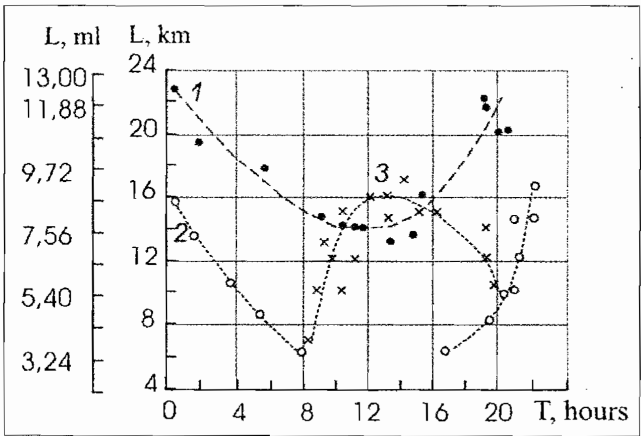

Fig. 5. : (binocular observations)

The data of field observation of the laser beacon (1), regular marine lights (2) and unlit marks (3) functioning in daylight

Development of the LANAIDs

For the further development of works and understanding of tasks to be decided by LANAIDs by some Russian R&D organisations a small-scale commercial set of two- and one-position laser leading beacons was made.

Some prototypes of the one-position laser leading beacon custom-made for the Hydrographic Enterprise of the Transport Ministry, were installed in Dudinka and Cove of Providence ports. Their parameters are given in the Table.

The typical location plan of this beacon in the Siberian river mouths is given in **Fig. 3** for the river Ob'. The conditions of coastal navigation here are characterized by extending up to 15 miles or more and narrow channels. One-position laser leading beacons provide the solution where there are difficulties in establishing range lights on some channels.

In **Fig. 4, 5** the data detectable distance (L) is given, obtained as a result of long-term field testing operation depending on time of day and a meteorological range of 8 km.

In **Fig. 6** the exterior of the one-position one colour laser leading beacon with a raised mantle and its assembly are shown.

In the early 1990s the Principal Department of Navigation and Oceanography ordered the prototype of a two-position laser leading light and this was designed.

Ayudas a la Navegación por láser (tecnologías)

Este es el segundo de dos artículos escritos por el Dr Gennady A Kaloshin, Director de Investigación del Instituto de Óptica Atmosférica [Institute of Atmospheric Optics SB RAS, Tomsk] y el Capitán Aleksandr I Gordienko, Jefe de Departamento del Departamento Principal de Navegación y Oceanografía de San Petersburgo, Rusia. En el Boletín IALA 2003/3 ya apareció un artículo anterior de estos autores con el título Ayudas a la Navegación por láser (metodologías).

El empleo del láser como fuente de un rayo de luz estrecho en las balizas aumenta considerablemente la distancia de detección en áreas en las que la luz tradicional no es visible, como por ejemplo aquéllas en las que la polución atmosférica es alta. En el presente artículo se publican los resultados de las investigaciones llevadas a cabo con Ayudas a la Navegación internas por láser (LANAIDs). Las características se evalúan por comparación, y se muestran los resultados de estudios de campo, así como los problemas encontrados durante su uso y perspectivas de desarrollo en un futuro.

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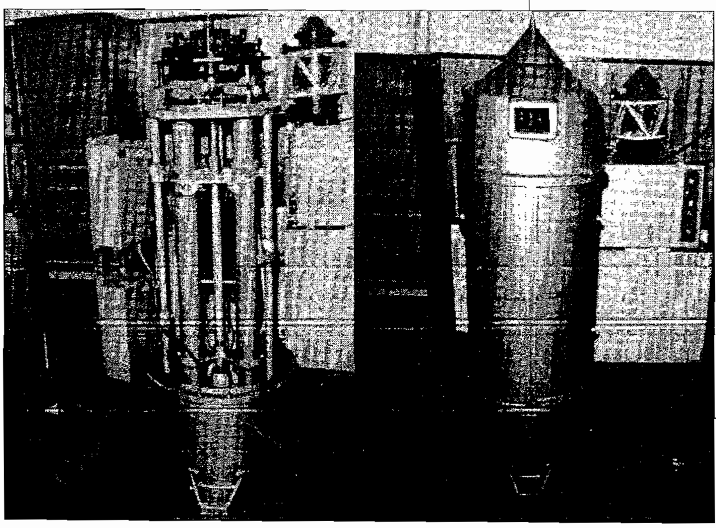


Fig. 6. Appearance of the one-position, one colour laser leading beacon: left – without mantle, right – as assembled

The beacon was intended for positions, where the visibility of a leading light was limited by port buildings. The characteristic two-position monochrome leading beacon is listed in the Table, and the location arrangement plan is shown in **Fig. 7**.

One of the last domestic developments is the experimental prototype of a one-position two colour laser leading beacon (the Table). The location arrangement plan is exhibited in **Fig. 8 a), b)** and its appearance is given in **Fig. 8 c)**.

Of particular interest is the position finding instrument, which principal operation is shown in **Fig. 9**. The prototype of this laser angular measuring device is used for determining the location. The device consists of two separate coastal posts and the onboard photo detector. Two laser beams (reference and information) are rotated in the horizontal plane at the coastal post. The beams cross on the reference (zero) direction line. The time interval between the beams, which unambiguously characterise the direction to the coastal post, is detected onboard the ship. The navigation problem is to be solved from two directions and the distance between the coastal posts.

The results of sea tests have shown that the accuracy for determining the direction is one minute of arc at the level of three standard deviations, and then the distance of finding the post is 5 km if the 20 mW He-Ne laser has been used.

One of the perceived directions LANAID efficiency raises is their use of semiconductor lasers with electronic initiation, which allows the refusal of electromechanical scanners, offered by R&D Institute «Platan» [16, 17]. The principal of operation of a given laser is based on the energy conversion of an electronic stream in a semiconductor mono crystal used in optical radiation. The location arrangement plan of this leading beacon and the operational principle is similar to the two-position laser leading beacon **(Fig. 10)**. The one post beacon exterior and its tube are given in **Fig. 11**.

It is necessary to note that all domestic samples of the laser beacons satisfy the Russian National Standard for laser safety.

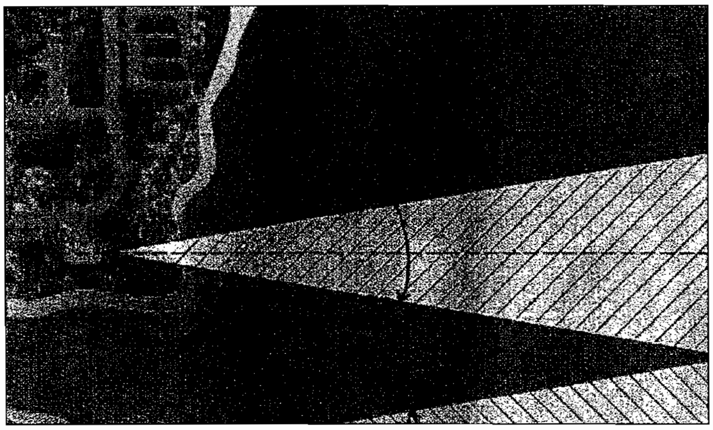
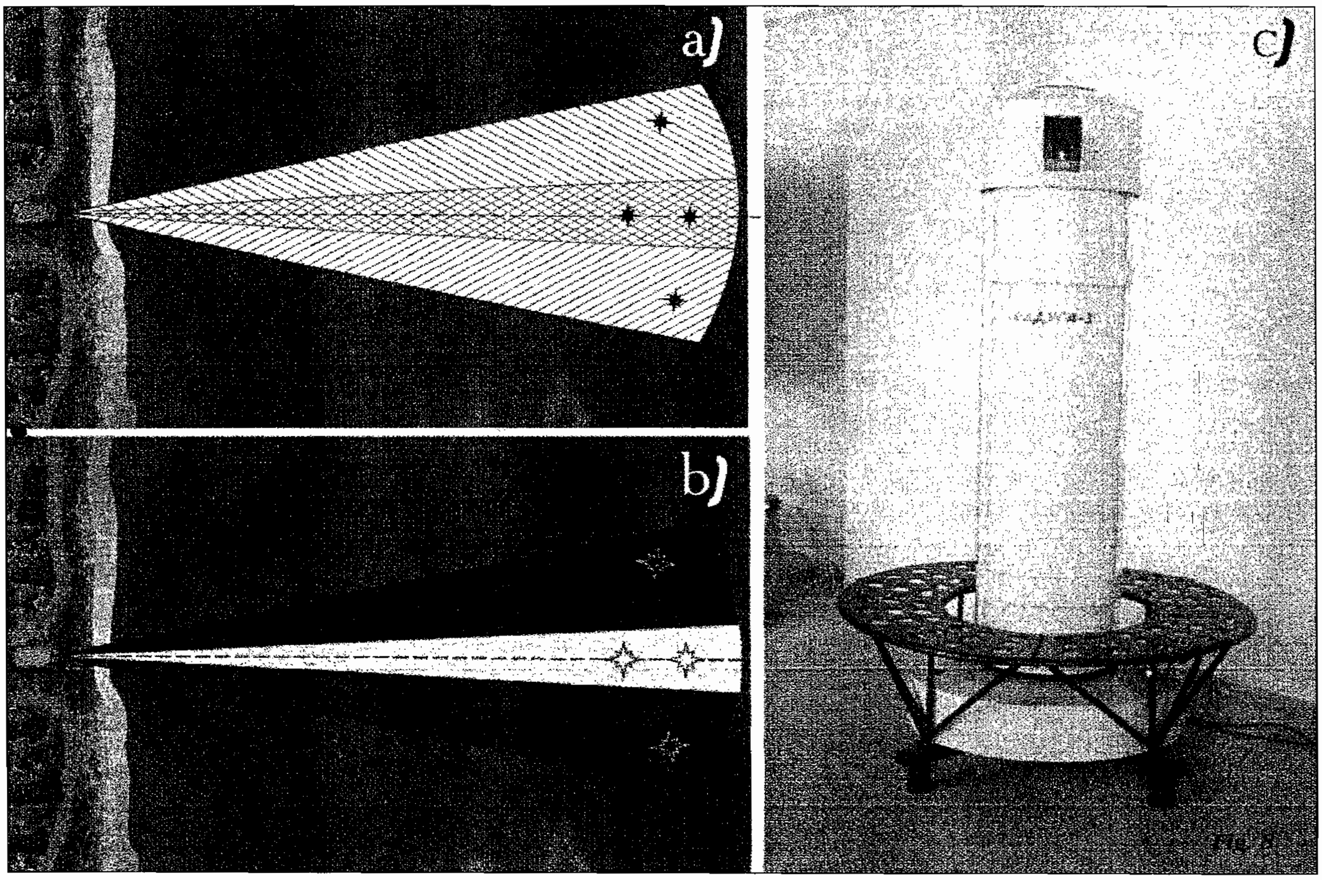


Fig. 7

Fig. 7. One colour, two-position laser leading beacon: flashing light colour – red

Fig. 8. Two colour, one-position laser leading beacon. Flashing light colour: a) red, green; b) red, green, yellow; c) appearance



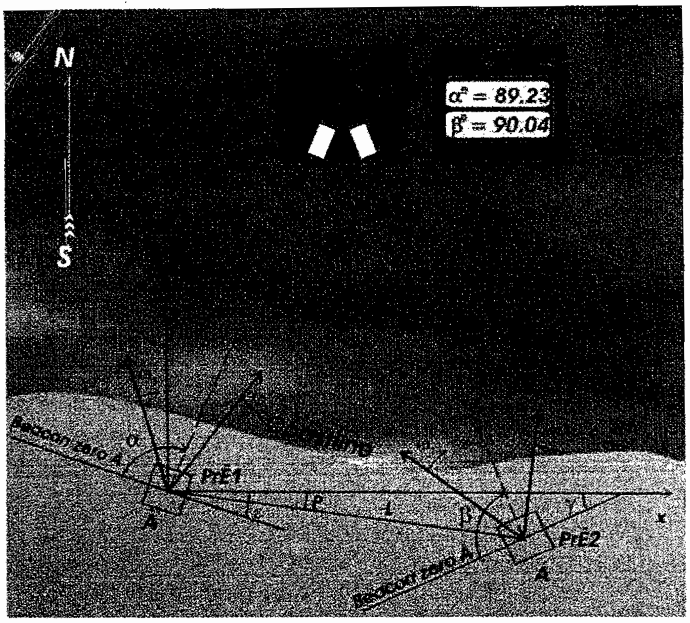
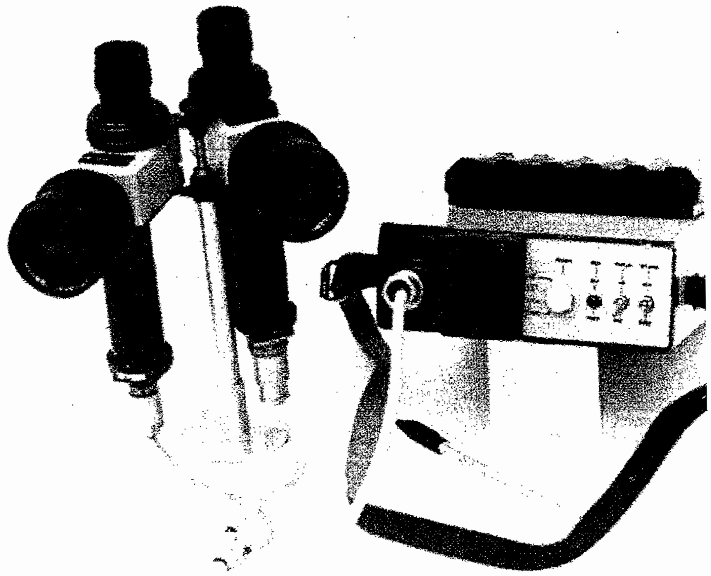


Fig. 9



Results and problems of practical application [18]

Advantages.

Numerous and continuous sea tests, field testing and the comparative analysis of characteristics of the table show the following. By common opinion, the installation of laser leading beacons considerably improves the conditions of coastal navigation on range especially at low visibility and at twilight, when the conditions of natural illuminance are not favourable for the observation of lights and marks. The guiding code is recognized as close-cut separation and the deviation from a center line is determined confidently. In twilight the detection distance of the laser light source is much higher, than regular lights and leading marks under any conditions of visibility. This circumstance is specially important for navigation in the Arctic Seas, with continuous twilight, especially where in Autumn and Spring these periods are lengthy. The output on the center line in a long-distance range at transition from one or other range does not create difficulties. For two colour one-position laser leading beacon two flashes characterize each point of the sector with different time gaps between them.

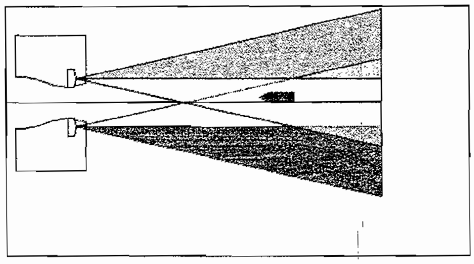


Fig. 10

Disadvantages.

Each type of LANAID has disadvantages along with its doubtless merits. In spite of the fact that the skills of practical coastal navigation are made at short notice, there are also some psychological problems connected to the absence of back range.

For laser beacons, as well as for regular lights, it is necessary to distinguish daytime and night detection distances. In clear solar weather at a high air transparency the detection distance of unlit marks is higher than those of the laser range.

For the one-position, one colour laser leading beacon the navigational data within the boundaries of each of three created sectors do not vary. At transition from sector to sector it varies by a significant leap.

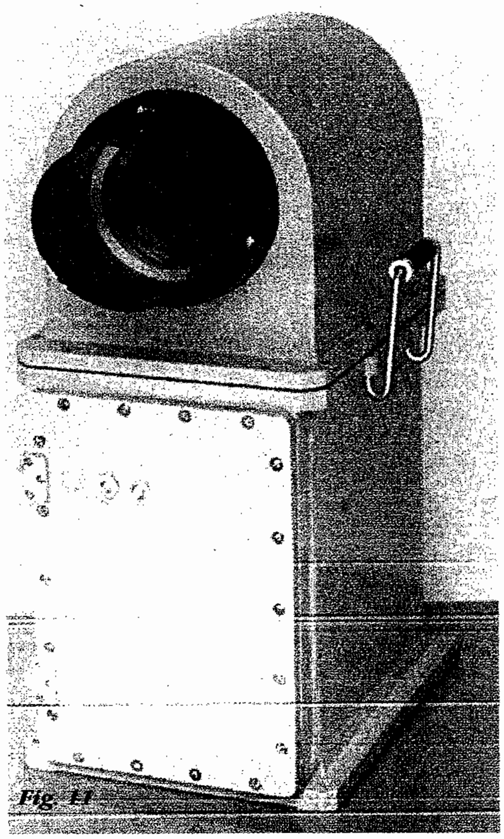
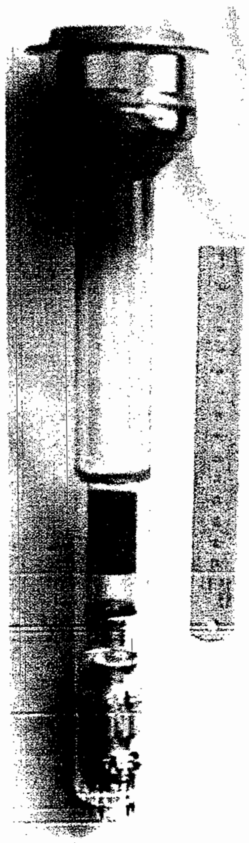


Fig. 11



In the two-position leading beacon the navigational data is represented by two flashes followed one after another from the left (right) and right (left) beacons (relative to the center line). The smaller detection distance as contrasted with the one-position beacon is explained by the low output power of the lasers used.

The beam «Glissade» laser system has an exceptional sensitivity near the center line. However it is visible only in night conditions due to the principle of its construction. In severe conditions where the visible range is of 5km or less the multiscattering background from the fixed beam considerably worsens the sensitivity of this type of range. Besides, the small angular size of orientation sector limits manoeuverable capabilities.

The one-position two colour laser leading beacon is free from these indicated defects. Different colours mark lateral sectors of this beacon: red and green remove ambiguity in the determination of the site of evasion from the center line. Besides, the narrow central zone is continuously marked either in red or green. It removes indeterminacy in the site of evasion in a central zone concerning the center line. The guiding code varies within the limits of sectors.

As it is seen from the Table the greatest detection distance is relative to one-position beacons. The two-position beacon and the laser range "Glissade" have essentially smaller detection distances, while the detection distance of one-position beacons makes 1.5 - 2.5 meteorological sight distances Sm. The field testing has shown that at equal power consumption the one-position beacon can be seen over a greater range when compared with regular lights by more than 30 per cent.

Perspectives

As a whole a laser light source by spectral radiant intensity considerably exceeds other known light sources. Unfortunately, the cost of lasers still remains high. However doubtless optimism calls the fact that the lifetime of lasers usable in LANAIDs permanently grows. Now it is used for some thousands of hours and among other things, it provides significant operating economies.

As with most prospective development it is necessary to consider the prototype of one- position two colour laser leading beacon [18]. The design solution of the given beacon allows the determination of the size deviation from the center line in lateral sectors. Besides, there is a capability of redistribution of radiation energy by orientation sector [12-14]. This circumstance alongside a light mode optimization will allow one to increase the detection distance of the beacon [19, 20].

At the present time the vast nomenclature of methods is being developed. The different versions of LANAIDs, enable solutions to be derived with trials of diverse aids to navigation on fairways.

The problem on expediency of laser range application should be solved from specific conditions of floating aids to navigation and their maintenance as well as safety, technical possibilities and economic efficiency of all aids to navigation. In a number of cases the greatest effect from laser leading beacons will be obtained with their simultaneous use with other kinds of aids to navigation. So, for example, for one-position laser leading beacons the narrowing of an orientation zone at the approach to the beacon is characteristic as it is at all sector lights. As a result an exit on the center line and the holding in it of a very large vessel could appear to be inconvenient. In this case it is expedient to indicate by floating aids to navigation the point of the beginning of a manoeuvre on an exit in a leading zone and to shield edges of the channel or border of a fairway.

In other cases the laser range can successfully be replaced with a High Luminous Intensity Direction Light, for example the PEL sector light, because it has essentially larger detectable distances and allows the viewer to determine how far a vessel is from the centerline of the channel.

One-position laser ranges are expedient for establishing in those places where:

- it is necessary to supply long detection distances of the range and for them to stand out against a complex lighting background;
- the construction of back range is impossible;
- for maintenance to the approaches to berths as part of maritime civil engineering and dredging works;
- during cable laying operations;
- to mark barriers in channels and fairways;
- in all other cases, where high accuracy of a heading indication or marking on the surface of the water lines, borders or local points as necessary. ■

Los autores realizan una introducción al tema y listan las referencias publicadas por la Guardia Costera de los Estados Unidos de América, Krupp Atlas Elektronik de Alemania, la Guardia Costera de Canadá, la Guardia Costera de Japón, el Instituto Nacional de Óptica francés [French Institut National d'Optique] y algunas organizaciones de investigación y desarrollo rusas. Debido a que es monocromático y posee una alta liminancia espectral, las Ayudas a la Navegación por láser son fácilmente visibles e identificables contra la luz de fondo y el pequeño diámetro del rayo de luz, combinado con la alta concentración de energía óptica, permite la creación del símbolo de navegación necesario empleando únicamente una posición.

Se desarrolla el concepto, las características indispensables de las fuentes de luz para las LANAIDs, así como su desarrollo, tecnología de escaneado, resultados y los problemas surgidos durante su aplicación práctica.

The Table Specification of the Laser Leading Beacon

–	The name of characteristics	Two position	One position	"Glissade"	One position two colour
1.	Character of navigation information	Flash, 0.2-0.7 Hz; pause-1-3 s. One colour	Flash, with pause; 1-10 s. One colour	Continuous, One colour	Flash, with pause 1-10 s dichromatic
2.	Quantity of orien. sectors	One	Three	Extensive line guiding	Three
3.	Adjustment angle in zones, degrees of arc	Azimuth-0.5-5; Angle of elevation-0.5-3	Azimuth – 0.1-1.2; 0.1,-3; angle of elevation 0.5-5.	-	Azimuth: centre sector-10 angle min., lateral-0.1-3.5. Angle of elevation-0.5-5
4.	Radiation wavelength, µm	0.63	0.63	0.64	0.61-0.66 0.46-0.52
5.	Radiation output power, µW	4-10	15-25	800	45
6.	Range of visibility: day, night	1 Sm, 2 Sm,	1.5 Sm, 2.5 Sm,	- 1.3 Sm,	1.5 Sm, 2.5 Sm,
7.	Accuracy of pilotage, angle minute of arc	3-7	1 near a channel edge at the 3σ	1 meter	1 near a channel edge at the 3σ
8.	Power consuption, watt	550	Average - 30	10000	1500
9.	Enviromental conditions, deg.C	40; - 40	35; - 50	40; - 30	40; - 50
10.	Lifetime (time before the first rejection), hours	5000	3000	500	5000
11.	Mass, kg	76 - one position	180	500	---
12.	Construction	Two position	One position	1-3 position	One position
13.	Cost, $ US	10.000	30.000	50.000	50.000

Note: Sm - meteorological range of visibility.

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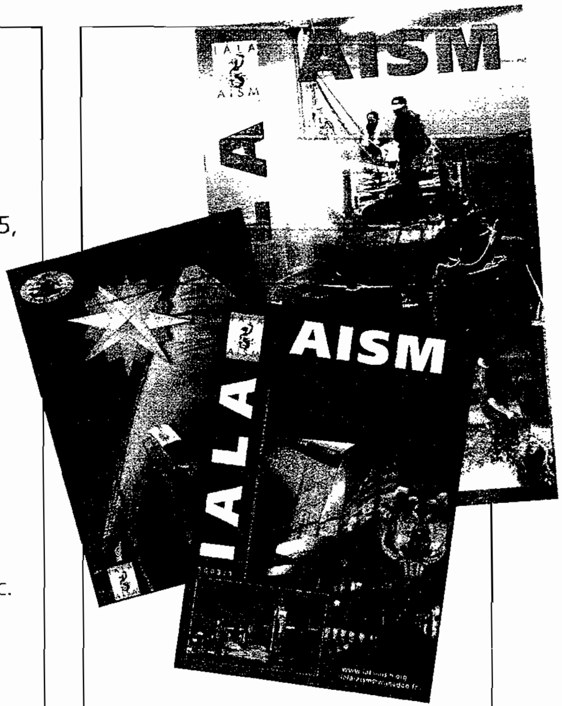

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The best results are achieved from colour prints or colour transparencies or very fine quality drawings or other graphic items than can be scanned.

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