LASER REVOLUTION AND ITS PERSPECTIVE DIMENSIONS

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ABSTRACT

Over the past decade, the considerable range of laser surveying equipment has made it possible to fulfil a wide variety of tasks. The practicing surveyor should now be conversant with these various types of equipment, their particular applications and what their limitations are, both practically and economically. For this purpose, a comprehensive research is presented in an attempt to furnish thorough understandings of all the aspects associated with the laser surveying field. This study will include the laser theory, refraction, incorporation and use of laser surveying devices, techniques and applications. The potential source of danger and the serious repercussions is also referred to, and accordingly, an understanding of the vital safety consciousness of the operatives and the laser safety guidelines is indispensable. The paper is concluded with recommendations to fulfil confident use of laser surveying instrumentation without any degree of wariness.

INTRODUCTION

Most beliefs recognise the laser as being destructive and sinister and that it must be avoided; this is definitely untrue. The spectacular achievements in laser development is certainly most vivid.

The surge in laser research commenced with the primitive solid-state ruby laser which emitted powerful pulses of collimated red light. The helium-neon (HeNe) gas laser was then introduced operating with an infra-red output. Also the semiconductor laser appeared using a gallium arsenide semiconductor. Today, the laser has established itself as a practical and sophisticated tool, passing its embryo stage and having become extremely robust and reliable. There is a rapid development in equipment and techniques as lasers are applied to the establishment of reference directions, reference planes (vertical, horizontal and sloping) and to the measurement of distances. This hectic rush still remains to develop new equipment and investigate further applications to present to the potential user of surveying instruments.

THE LASER THEORY AND CHARACTERISTICS

Theory

Light amplification by the stimulated emission of radiation gives "laser" its name. The process of stimulated emission enables the laser to emit a very intense monochromatic radiation that travels as a very narrow beam for considerable distances before it spreads out. No other light source can be compared with a laser which squeezes a massive amount of energy into its narrow beam.

Since it is possible to produce lasers with infra-red and ultraviolet outputs, the statement that the output from a laser is described as a beam of light can be misleading. The laser emits some form of electromagnetic radiation rather than simply light. From the electromagnetic spectrum in Figure (1), the boundaries between different types of radiation are shown to be quite distinct, whereas in practice these tend to overlap. Lasers fit into the optical part of the spectrum which extends from the infra-red, through the visible, to the ultraviolet regions.

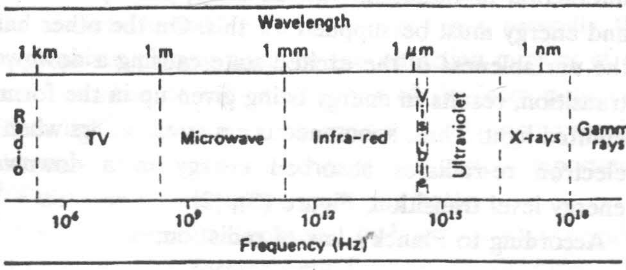

Figure 1. Electromagnetic spectrum.

Optical electromagnetic radiation can in some cases be treated as a beam of discrete energy particles called photons, which gives rise to the quantum theory of light. When light interacts with matter, it is the quantum nature which predominates rather than the wave nature. The operating principles of lasers are described in terms of quantum theory, but their outputs are nearly always treated as electromagnetic waves.

As known, each atom possesses a characteristic set of energy levels giving rise to its physical properties. In a single atom, each electron in a given orbit possesses a definite amount of energy corresponding to the orbit, and the majority of electrons would normally be in the "ground state" which is the lowest energy level, as displayed in Figure (2).

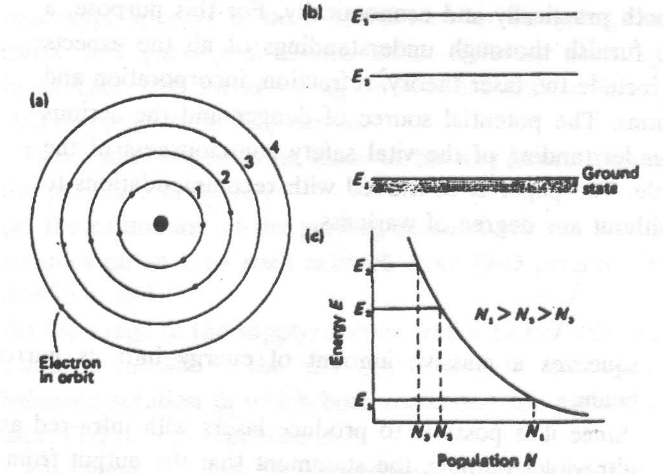

Figure 2. (a) Electron orbits; (b) Energy level diagram; (c) Population diagram.

For lasers the concept of energy level is most important, as laser operation takes place between electronic transitions at different energy levels in an atomic structure. When an electron is activated and raised from one energy level to excited states of higher energy levels, due to the interaction of radiation with an atom, absorption occurs and energy must be supplied for this. On the other hand, the unstableness of the excited state causing a downward transition, results in energy being given up in the form of emitted light. Thus, spontaneous emission occurs when an electron re-radiates absorbed energy in a downward energy level transition, Figure (3), [2].

According to Planck's law of radiation:

$$\Delta E = E_2 - E_1 = hc/\lambda$$

where ΔE is the difference between the two levels E_1 and E_2 at which the electron has moved, h is Planck's constant and c the speed of light. Both energies, absorbed or emitted, must be equivalent to ΔE. It is also apparent from the equation that the energy associated with transition increases as the wavelength λ decreases.

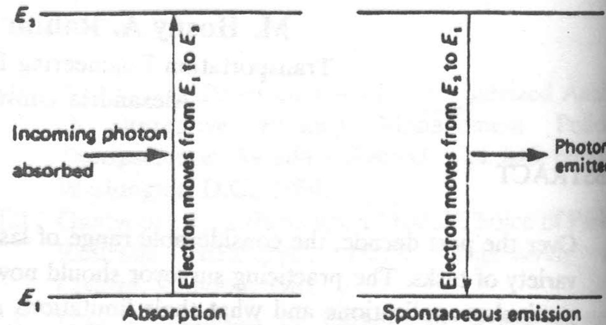

Figure 3. Absorption and spontaneous emission.

In the process of stimulated emission an incoming photon interacts with an excited atom causing an electron to give up its energy and fall to a lower level. The result of this interaction is that one photon is incident on the atom and two photons emerge, both of which are of the same frequency and travelling in the same direction, Figure (4).

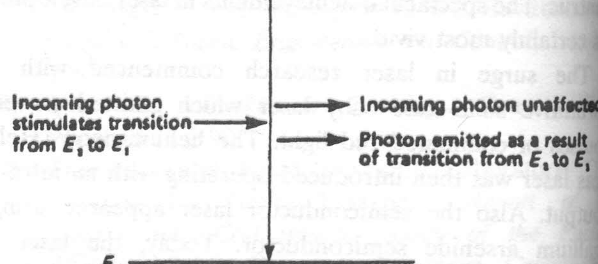

Figure 4. Stimulated emission.

There is more absorption than stimulated emission if the atoms in the ground state exceed those in the excited state. This occurs when the populations of two energy levels are in thermal equilibrium, [1]. If this process is to be reversed such that a greater emission occurs compared with absorption, then a population inversion is required.

The process of the lasing action may be demonstrated by the simple ruby laser which consists of a helical electronic xenon flashlamp mounted along the axis of a ruby laser rod as the active material, shown in Figure (5). The flashlamp output is dissipated as heat, providing the "pumping radiation". The resulting absorption excites or pumps some of the ruby atoms from the ground state E_1 to an intermediate energy level E_3, and then decay to level E_2, radiating heat. Some of these atoms further decay to the ground state thus causing spontaneous emission of photons, Figure (6). The continuous emission of energy from the flashlamp causes an increase in the atoms reaching E_2 through E_3 and thus, an increase in the fluorescent output. Population inversion may occur if the spontaneous transition from E_2 to E_1 is low, i.e. if the electrons remain for a considerable time in the upper E_2 metastable state. This may be with a sufficient pumping radiation which causes the number of electrons in E_2 to exceed those in E_1. Laser action is not possible without a population inversion, [2].

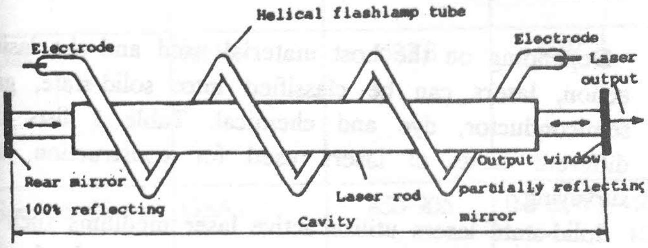

Figure 5. Ruby laser rod with helical flash tube.

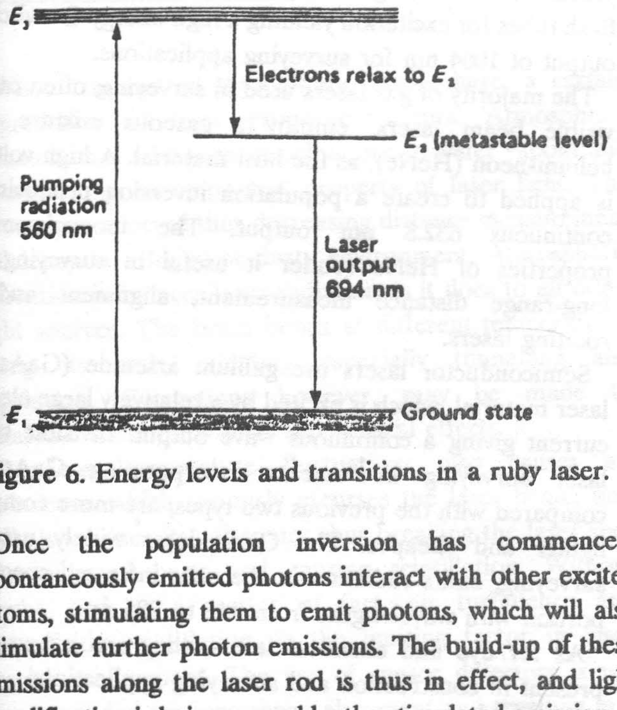

Figure 6. Energy levels and transitions in a ruby laser.

Once the population inversion has commenced, spontaneously emitted photons interact with other excited atoms, stimulating them to emit photons, which will also stimulate further photon emissions. The build-up of these emissions along the laser rod is thus in effect, and light amplification is being caused by the stimulated emission of radiation, which is the laser concept.

Two mirrors fixed perpendicularly to the rod axis and forming a laser cavity, as shown in Figure (5), will enhance the accumulation of stimulated emissions. One mirror totally reflecting, while the other partially reflecting a small but intensive amount of incident energy at each pass (< 1%) as the laser output. The mirrors provide positive feedback and it is possible for the laser radiation to build up rapidly to a very high level.

The previous was a capsule account of a three-level laser system which requires a high pump energy to maintain the population inversion. This disadvantageous requirement may be overcome by a four-level system, Figure (7). Active materials are selected where relaxations 4-3 and 2-1 occur rapidly, so that level E_2 remains empty and it is easy to fill level E_3 with a sufficient number of electrons. Most lasers are four-level systemed.

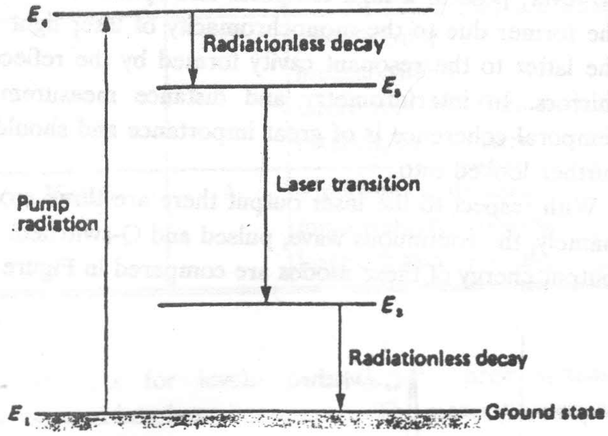

Figure 7. Four-level laser system.

Characteristics

The output of an incandescent light source covers a broad band of wavelengths, whereas the highly monochromatic laser has a much less spectral bandwidth which is an important criterion. This is due to the laser action which depends on first, the wavelength governed by the metastable and the lower energy levels, secondly, the appropriate placing apart of the reflecting mirrors at an exact number of half-wavelengths of the laser radiation. Since light dispersion is less for a monochromatic source, the monochromacity of laser light is of utmost importance for distance measurement over long paths.

Unlike conventional sources, the laser has a low angular divergence. The former emit light in all directions, the beam being not parallel, such that the intensity decreases proportionally to the distance square. Whereas in lasers this significant characteristic is due to the laser process itself where the cavity mirrors are aligned so that only light very close to the laser axis builds up. The laser's low divergence and high intensity permit a narrow beam transmission with an accurate detection of the beam centre, even after considerable attenuation, over long distances (alignment and rotating beam lasers). In accordance,distance measurements of well up to more than 20 km. is applicable.

Temporal coherence is when all parts of a wavefront are in phase along the light beam direction, whereas spatial coherence is when all parts of a wavefront in a plane perpendicular to the propagation direction are in phase. Ordinary light sources have no temporal coherence, but may be designed to have spatial coherence. Lasers however, possess a high temporal and spatial coherence, the former due to the monochromacity of laser light and the latter to the resonant cavity formed by the reflecting mirrors. In interferometry and distance measurement, temporal coherence is of great importance and should be further looked into.

With respect to the laser output there are three modes, namely, the continuous wave, pulsed and Q-switched. The output energy of these modes are compared in Figure (8).

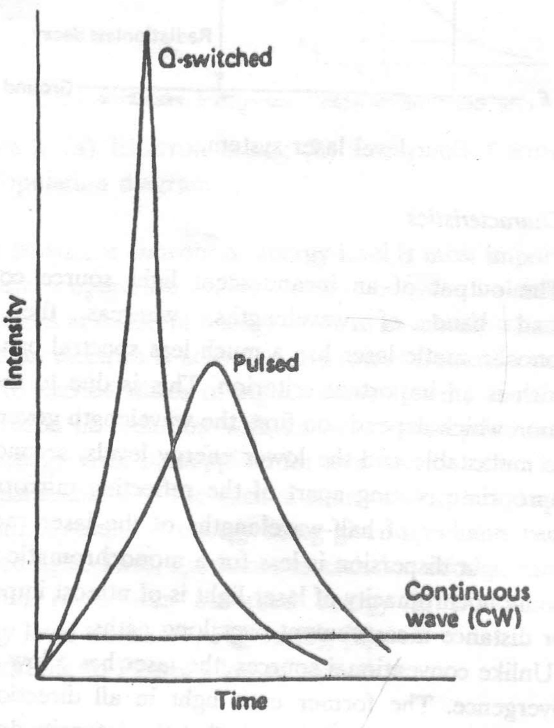

Figure 8. Laser output modes.

C.W. lasers have low outputs but their operation only requires a small input energy. On the other hand, in pulsed lasers the avalanche effect in the laser cavity produces a high power output and duration and frequency related to the input energy. As for the Q-switched mode, it enables the laser to produce a high peak power pulse of very short duration. The three previous laser output modes are widely used in surveying as illustrated herein after.

From the foregoing, laser is definitely distinguished from all other light sources by its unique spectral purity, low angular divergence,high coherence and high output intensity. All these previously discussed refined characteristics lead to the determined study of their perspective uses in surveying fields.

TYPES OF LASERS

Depending on the host material used and the lasing action, lasers can be classified into: solid-state, gas, semiconductor, dye and chemical. Table 1 lists the different kinds of lasers used for construction and surveying.

Solid-state lasers utilize active laser mediums such as ruby, neodymium in glass (Nd : glass) and neodymium in yttrium aluminium garnet (Nd : YAG), with electronic flash tubes for excitation yielding a high energy Q-switched output of 1064 nm for surveying applications.

The majority of gas lasers used in surveying, often called visible beam lasers, employ a gaseous mixture, the helium-neon (HeNe), as the host material. A high voltage is applied to create a population inversion producing a continuous 632.8 nm output. The monochromatic properties of HeNe render it useful in surveying for long-range distance measurement, alignment and in rotating lasers.

Semiconductor lasers use gallium arsenide (GaAs) as laser material, which is excited by a relatively large electric current giving a continuous wave output. Invisible beam laser surveying instruments incorporating GaAs, as compared with the previous two types, are more compact, lighter and cheaper. The GaAs laser widely used in surveying, emits radiation in the near infra-red spectrum portion with wavelengths from 845 to 905 nm.

As for dye and chemical lasers, they are not used at present in construction and surveying applications.

BEAM PROBAGATION AND REFRACTION

HeNe gas laser beams propagate in a well-defined Gaussian symmetry [2] across their propagated wavefronts. Such symmetrical nature of gas laser propagation through the atmosphere is extremely useful in alignment and rotating lasers as it enables the accurate detection of the laser's beam centre. In solid-state and semiconductor diode lasers however, their outputs are not symmetrical.

Table 1. Characteristics of Lasers used in surveying

Classification	Laser	Wavelength (mm)	Typical output power		Typical beam divergence (mrad)	Typical efficiency (%)	Applications
			c.w.	Pulsed			
Solid-state	Nd : YAG/glass	1064		10^6 W	5	1	Timed-pulse distance measurement (rangefinding); depth sounding from aircraft
Gas	HeNe	632.8	5 mW		1	0.1	c.w. distance measurement; interferometry; fixed and rotating beam lasers
Semiconductor	GaAs	850-905	0.5 mW	up to 100 W	25x125	4	Timed-pulse distance measurement; rotating lasers; terain profiling

When transmitted through the atmosphere, a certain degradation of laser properties occurs. Atmospheric attenuation is a frequent problem due to water vapour and consequently, an important property of laser light. The intensity is affected thus decreasing distance measurement efficiency in a foggy or dusty environment. Atmospheric refraction influences laser radiation as it does to all other light sources. The beam bends at different temperatures along its path, affecting especially tunnelling and pipelaying. Corrections however, may be made to eliminate these horizontal and vertical effects.

Random temperature fluctuations also causes air turbulence which seriously excurses the laser beam, and will also reduce its coherence thus breaking the laser spot into pulsated parts and causing scintillation. Without doubt, and as a matter of fact, air turbulence and accordingly scintillation, is the limiting factor in laser precision alignment. The use of sensor detectors is not recommended for long-range alignment and levelling in a turbulent atmosphere at ranges in excess of 150 ms.

LASER SURVEYING INSTRUMENTS, TECHNIQUES AND APPLICATIONS

All lasers used in a surveying instrument contain an arrangement of lenses (beam expander), the effect of which is to increase greatly the beam collimation and its diameter. As for levelling, there are three systems incorporated into laser instruments. The manual system as conventionally known. Secondly, systems using optical compensators have a small correction range of ± 15′ meaning that manual levelling is required to within ± 15′ and that frequent checking, which is a handicap on site, is also required to avoid possible dislevelment. Finally, self-levelling systems are capable to self-level within a range as large as ± 8° to the horizontal or vertical. The optical compensator is more accurate producing a plane within 5" of the horizontal compared with 5-10" for the electronic self-levelling system.

Laser surveying instruments being airtight and waterproof are prone to internal condensation inside the housing due to variance in temperature. Condensation would affect the electronic circuits and laser optics, and would also cause safety problems. To avoid condensation build-up, the instruments are nitrogen purged thus removing all oxygen inside and preventing air from being drawn in.

Finally, laser detectors are used where visual inspection of the beam is not possible (infra-red diode lasers). They define the position of the beam and accurately locate the centre of a fixed or rotating beam laser. In addition, this sensor detects the laser return signal in distance measuring instruments. Photosensitive cells are arranged in various configurations so that a long "capture length" and a great "angle of acceptance" may be achieved. A precision of ±1 mm can be easily achieved.

Laser surveying instruments fall into three categories, fixed beam, rotating beam or distance measurers.

I- *Fixed Beam Lasers*

Fixed or single beam laser surveying instruments project a HeNe narrow beam of visible light clearly seen on targets under all prevailing light conditions. They are preferably used in night operations when their range increases considerably. They are also ideal for linear and vertical alignment purposes where the beam direction is fixed while in use. Their two main advantages over conventional instruments are the production of visible beams and the requirement of only one operator (thus speeding up operations, reducing human errors and enabling more consistent readings to be obtained). Their uses are analogous to conventional string-line, plumb-line or line-of-sight methods. A further advantage is the possibility of the operator to safely manoeuver through the beam without disrupting the operations. Typical examples of this category of instruments are laser eyepiece attachments, laser theodolites and levels, and alignment lasers, [3], [4], [5] and [6].

a- Laser eyepiece attachments :

It is an add-on device fitted to ordinary optical theodolites, levels or plummets converting them to laser instruments. This eyepiece does not in any way impede the use of the instrument fitted to. It simply generates the red beam through the instrument telescope along the optical axis. The beam acts as the line of sight. An advantage here, is that the bright red spot formed on the target and which can be focused to a very small well-defined sharp dot, will thus increase the accuracy of observations and measurements taken to it. A disadvantage is that refocusing is required for variable distances. The simple interchanging of the standard telescope eyepiece with the Kern or Wild simultaneous viewing attachments (i.e. the operator is able to observe while the beam is being generated) will allow observations ranging from 300 ms by day-time to over 600 ms at night.

A second type of attachment is a non-simultaneous viewing add-on, which generates a laser beam parallel to, rather than along, the optical axis. Thus, it does not have the facility to look along the line of sight simultaneously. It is meant for use when a laser distance measurer is being used to measure distances without prisms. The reading range of the Ahrin accessory model is 40 ms by day and 100 ms by night.

The versatility of these attachment devices, in that they can be fitted to various optical instruments, may be illustrated by their way of use in construction surveying applications [4]. The verticality of tall buildings and mineshafts may be controlled by attaching a laser eyepiece to a precision optical plummet. Floor-by-floor construction in multistorey buildings may also be controlled by a defined visible vertical reference line projected from the laser, and which passes through holes in intermediate targets placed on completed floors. Upward and downward plumbing can be carried out. Besides utmost accuracy, an advantage of laser plumbing is that only one operator is required thus avoiding the problem of lack of communication in two-operators conventional plumbing.

Considering the monitoring of deformation measurements, laser eyepieces may be further used in measuring runway surface deformations. The detection of the beam on a special levelling staff will yield results within 2 mm accuracy. Also, a sophisticated technique may be applied for the detection of structural deformation, such as in bridges, while in course of construction. A laser eyepiece attached to a theodolite are set up and a beam is emitted to a receiver (photodetector) placed on one of the partly constructed piers of the bridge. The photodetector in turn, will describe the x,y position of the laser dot. Deformations due to static and dynamic loading will cause a change in these coordinates which are recorded automatically.

The latest use of laser eyepieces is in remote measuring systems to calculate the three-dimensional positions of points on structures without the need of touching the object being measured. A laser eyepiece is fitted to a theodolite providing visible spot targets of known position and are intersected by another theodolite. This, together with observations to a scaling bar, enable the fixation of its three-dimensional position. Extremely awkward surveys may be carried out with comparative ease, such as in coordinating the face of a dam during deformation measurements.

b- Laser theodolites and levels:

These instruments [3] are purpose-built, the laser tube being incorporated as an integral part of the device. The beam is routed into the telescope through a series of prisms and passes along the optical axis, thus possible errors due to parallax are totally eliminated. All instruments are designed for simultaneous viewing. Unlike the laser eyepiece attachments, they can be used conventionally when the laser beam is turned off, whereas the former have the centre cross in the telescope removed. The power output of all lasers in this group conforms to that of the Class 2 safety category as discussed further on.

All applications are based on the ability of these instruments to produce a visible red spot and a visible red line. Single-person operation can thus be undertaken; the beam centre can be highly detected since it can be focused to as small as 10 mm in diameter at 100 ms. Accordingly, uncertainties in signalling instructions can be avoided even if two operators are used.

Typical laser theodolite applications are controlling tunnelling by determining the direction and gradient, and the positioning of moles. The beam is fired in the required direction and intercepted by a selenium cell device which converts it into control signals, thus activating the tunnel-boring machine to maintain the required direction. The effective range may exceed 400 ms meaning that relocation of the laser is necessary only at intervals of several weeks. Laser theodolites are also used to control pipelaying by aiming the spot along the pipe. A special target is fitted at the far end of the pipe and the beam travels either along or parallel to its centre line at the required grade. The pipelayer simply nudges the pipe until the spot coincides with the correct point on the target. Other applications such as checking the vertical alignment of H-frame and steel pipes, or centering the screw in shipbuilding, may be accomplished.

Compared with other laser instruments, the laser theodolite, level and eyepiece have some disadvantages :

1- With all the three instruments refocusing of the spot is necessary for different distances which is time-consuming.
2- The filter installed on the laser eyepiece to reduce glare darkens the view of the line of sight, which can be a problem indoors.
3- Laser theodolites and levels, also waterproof and shock resistant, could be severely affected due to prolonged use in a wet trench or exposure to dusty hot conditions in tunnels.
4- When controlling the direction of small diameter pipes, the operator has to lie on the ground to set the direction of the instrument.

These instruments should thus be restricted to projects of lax conditions and where the diameters involved are reasonably large. Purpose-built laser alignment devices establishing a constantly focused reference line and are waterproof and resistant to handling conditions,are preferably recommended for pipelaying and tunnelling control.

Laser theodolites, levels and eyepieces are, however, successfully applied to the monitoring of cracks on high buildings, surveying inaccessible points on the faces of dams, checking the gradients of pipelines, roads and railways, aligning column bases and controlling verticality and establishing levels inside buildings. Furthermore,their advantages over purpose-built alignment lasers are :

1- No offsetting of targets is required to allow for lateral or vertical displacement between the beam and line of sight, thus positioning of targets and control of machinery can be achieved much more quickly.
2- Their versatility in incorporating all the facilities of conventional instruments together with a visible line of sight.
3- They are lighter in weight and less bulky.

The latest sophisticated laser theodolite and laser level are known as the electronic Topcon ETL-1L and the Topcon LTS-3 respectively.

c- Alignment lasers:

They either incorporate their own built-in self-levelling system or designed to fit into conventional surveying instrument tribrachs to enable levelling to be achieved. Alignment laser techniques and procedures are mainly directed to controlling pipelaying, tunnelling,rail alignment and dredging.

Of all laser instruments, definitely pipe lasers used with special targets come as first rank where pipelaying is concerned. They are not affected by flooding and will function even if totally immersed, withstanding an exertion of 10 ms of water, and are used at a temperature range from -25 to +50° C. All pipe lasers contain a nitrogen-purged housing to prevent condensation. This instrument,however, conforms to the Class 3A safety category and requires great safety precautions. The beam diameter is about 10 mm with low angular divergence, thus no focusing is required and a working range up to 300ms may be easily achieved. Pipe lasers are also self-levelling and incorporate a warning system which beam is routed into the telescope through a series of prisms and passes along the optical axis, thus possible errors due to parallax are totally eliminated. All instruments are designed for simultaneous viewing. Unlike the laser eyepiece attachments, they can be used conventionally when the laser beam is turned off, whereas the former have the centre cross in the telescope removed. The power output of all lasers in this group conforms to that of the Class 2 safety category as discussed further on.

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A problem which may be encountered during pipelaying is the beam refraction along the pipe, which occurs when placing a warm pipe into a cold trench or vice versa, or when the top is exposed to sun heat and the bottom cooled by earth or water. A temperature gradient occurs due to hot and cold air pockets, and the beam deviates. This, however, may be overcome by special blowers flushing the pipe with air, or by mounting the laser on top of the pipe (external controlling). Also moving the laser along the pipe and close to the target as construction progresses, will decrease the temperature gradient.

The initial direction in establishing the line of a pipe can be set by adjusting the beam (with reference to the known level) at the correct level at the bottom of excavation. A theodolite mounted directly above the laser by optical plumbing, Figure (9), is pointed at the ranging rod defining the next manhole location, and after some excavation the theodolite is tilted downwards to give the line on the excavation wall. The required grade is set on the laser and the remote control device alters the beam direction until it applies with the correct line of the sighting theodolite.

The application of lasers to the control of pipelines is indeed advantageous over conventional methods. Laser beam alignment eliminates the need for sight rails, profile boards and travellers. Also, up to 30% more pipe can be laid in the same time, thus decreasing time consumption. In addition, the accuracy of the pipe laser (better than ± 10 mm in 10 ms) will limit excavation to the minimum depth and width required, thus preventing over digging and saving approximately 15% of bed material costs and labour reduction. Finally, the laser beam acts as a constant check during construction. Several pipe lasers are currently on the market, the AMA SLP and the Spectra-Physics Dialgrade 1220 are probably the best yet produced.

Tunnelling [5], which is a very specialized subject, is another field where lasers offer an ideal solution for precise alignment. Virtually all major tunnels, such as the Ahmed Hamdy tunnel linking Sinai with the motherland, are controlled using lasers. Two main problems arise when establishing tunnel control that seldom occur in pipelaying; the scale is much larger and the work is carried underground with all the inherent problems prevailing in such an environment as heat, humidity, water,dust, etc. These adverse site conditions and potentially hostile atmosphere may hamper the use of laser theodolites and eyepiece attachments, a purpose-built tunnel laser being therefore the ideal solution.

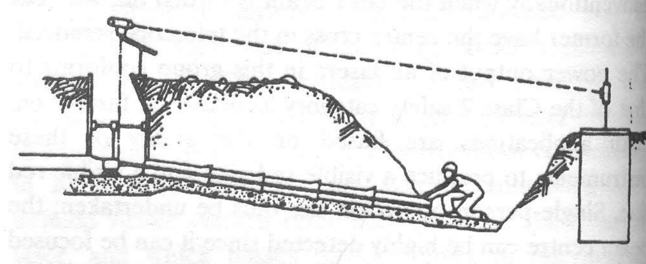

Figure 9. Setting the line for a pipelaser deep manholes and trenches.

Tunnel lasers are waterproof, shockproof, and dustproof, operating at temperatures ranging from -30 to 50° C. All are nitrogen-purged and some are vandalproof and even flameproof. For underground conditions lasers must conform to fire safety regulations. As regards eye-safety, tunnel lasers have a powerful output anywhere from a Class 2 category to a Class 3B category. It is strongly advised that before considering the use of a Class 3B tunnel laser, the safety guidelines discussed hereinafter should be carefully read.

In tunnel control constant levelling is not necessary, and the expense of including compensator or self-levelling devices is not justified for tunnel lasers, but instead the traditional manual system is used. Tunnel lasers also fit into special tribrachs which include horizontal and vertical angle systems, effectively turning it into a powerful laser theodolite such as the Spectra Physics LT4 Transit Lite. The beam can be pointed in predetermined directions without the need for an end-target. As for curved controlling, pentaprisms and beam deflectors placed at regular intervals, redirect the beam and enable curved drives to be monitored.

The line of a tunnel is established by mounting the laser on the tunnel roof with targets to define the required grade and direction of the tunnel. In a manually guided system the position of the spot with reference to the target centre indicates how far the drive is from the required line. Adjustment of the machine controls thus re-establishes the correct line. The use of lasers in this way can approximately save 15% of bed material by preventing overbreak. Advanced automatically guided systems are those in the ZED instruments for either straight or curved drives. The laser beam here is not targeted, but instead it is sensed by a special target unit containing an array of photosensitive cells covering a 300 mm x 300 mm area. These cells enable the precise measurement of the horizontal and vertical displacements of the tunnelling machine from the required line. Detailed information on the progress of the tunnelling is displayed on a screen : 1) The present position of the tunnel shield centre compared with the required centreline position. 2) "Roll" (rotation of machine about its longitudinal axis). 3) "Lead" (horiz. slewing of machine). 4)"Look-up" (vert. slewing of machine). 5) The predicted position of the tunnel shield centre at a predetermined distance (5 ms) ahead of the working. This laser tunnelling technique totally eliminates the collinear error which is of serious effect in tunnel alignment.

A self-checking facility against accidental or ground movements can be provided by passing the beam through a hole in an intermediate target to a final target, both being set up along the reference line. Surveyors involved with laser tunnel control spend a great deal of time checking for any undesirable movement and re-establishing the line. Thus, the laser and its targets should be securely located at solid stations to avoid movement. To improve the accuracy of setting out the tunnel lining ribs and to reduce time consumption, two lasers may be used instead of one, each being set up at the centreline level attached to the opposite tunnel wall.

Finally, and with respect to refraction problems, they may be overcome by minimizing the distance between the laser source and the final target. This can be achieved with the AGL Total Control Laser which actually has a facility for projecting the beam out of the rear of the tube in order that it can be accurately realigned with a previous target. Factors such as the atmospheric conditions, beam divergence and even earth curvature, govern the working range of tunnel lasers which may reach 800 ms. However, at large distances the laser spot becomes irregular in dusty, humid tunnels. In accordance, this reinforces a recommendation to consider an ideal maximum working range in the region of 350 ms.

Other applications of alignment lasers is controlling rail alignment. Conventionally, a huge tamping machine is used in monitoring and correction for any misalignment (even within a few centimetres) due to severe loads and stresses which may lead to derailments. However, a limitation of the machine is that it assesses straightness and level(smoothing process) of the track over its own length which is about 11ms, thus giving rise to a need for a longer alignment base. A technique, Figure (10), involve an alignment laser mounted on the centreline of a railwa bogie clamped to the rails and pointed at a sensor also o the centreline and fitted to the front of the tamping machine at the other end of the length that is to b smoothed (max.range between laser and sensor is 600 ms) The sensor constantly monitors the laser beam while th tamping machine slowly moves forward towards the laser The Laser Alignment Inc., Michigan, USA, has patente a lens technique producing a narrow vertical fan of lase light which can be detected by the sensor to within 6 mn over the full 600 ms working range.

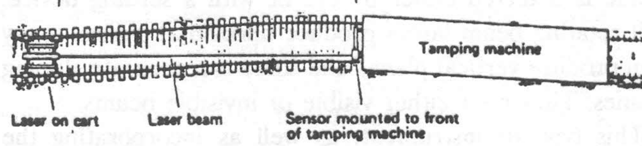

Figure 10. Rail Alignment technique.

The system provides great speed in the smoothing process and extends the control base from 11 ms to 60 ms thus enabling accurate smoothing in only one pass Although it is limited to straight and not curved tracks and that it checks the line and not the level, this system i a considerable improvement on conventional techniques.

Offshore control operations are of great difficulty whe using conventional instruments such as theodolites, sinc it requires the intersection of a moving target. However the principle of using fanned beams to monitor offshore work facilitates the problem. A fan lens generates fanned beam (horiz. or vert.) which defines any part of plane, and any movement in the floating platform can b accommodated,enabling the visible beam to be clearl seen. The lens expands the beam at a rate of 250 ms pe 1000 ms in the wide direction and 65 mm per 1000ms i the narrow direction. The working range depends strongl on prevailing atmospheric conditions and may reach up t 16 kms under normal weathering circumstances.

The potential of alignment lasers enables them to b used also in checking motorway surface levels b measuring the three-dimensional coordinates of points o the motorway surface, thus obtaining surface deterioratio information without disrupting traffic flow.

Also monitoring structural movement is possible using purpose-built movement detector attached to the structur along the beam path. Any structure movement wi correspondingly move the detector to an accuracy of ± 0. mm.

To attempt to list all of the applications of alignment lasers is indeed an impossible task, but it is ascertained that they can be successfully used in numerous specialized operations.

II- *Rotating Beam Lasers*

A rotating beam laser is a fixed beam laser fitted with spinning optics that rotate the beam through a full 360° coverage to stimulate a horizontal plane of light which continuously sweeps the site over a large area. This eliminates the need for frequent manual adjustment of the beam direction as in the simple fixed beam laser. The plane is detected either by eye or with a sensing device. All rotating beam lasers produce horizontal planes, many can produce vertical planes and some can generate sloping planes. They emit either visible or invisible beams.

This type of instrument, as well as incorporating the standard requirements of power supply, nitrogen-purging facility and self-levelling system, also incorporates unique features which include (i)the ability to rotate the beam, (ii) the facility of controlling the plane of rotation and (iii) the need to detect the centre of the plane.

A continuous beam rotation is maintained by using a rotating pentaprism. As for controlling the plane of rotation, a self-levelling system or a compensator system is incorporated to control both,horizontal and vertical planes. Also the elevation of the plane may be set or established by several methods. Inclination is controlled by built-in grade facilities as in the AMA SL-87 Compi which sets the desired grade automatically. Either a single slope (about one axis) or a compound slope (about two perpendicular axes) can be provided. Instruments currently available are capable of setting up to ± 10% of slope in increments of 0.001%. Finally, detecting the centre of the established plane of light will depend on whether a visible or invisible beam is produced. For a visible beam, accurate detection by eye is quite possible over short ranges. However, it must be aware that this may present some safety problems since all modern rotating visible lasers conform to the Class 2 or the Class 3A safety categories. Over longer distances, detecting devices are required. However, for an invisible beam, electronic laser detectors are the only means of locating the plane centre.

Visible beam instruments (HeNe) produce a beam of very low angular divergence such as that of the fixed beam laser, thus eliminating refocusing requirements over its working range, which is in excess of 400 ms. The pentaprism assembly fitted to the rotating laser allows for scanning up to 720 rpm and offers several modes of use: 1) It varies the speed of rotation which is necessary to obtain the best reference line. Too slow a speed or a too fast one will not accurately define the beam and accordingly, a trial and error method should be performed to give the best image. 2) Another function of the pentaprism is that its rotation can be stopped altogether and rotated manually, thus transferring the instrument into a fixed beam one used for alignment purposes. 3) In some instruments the detachment of the prism will provide the advantage of creating a fixed beam mode as well as a rotating beam mode. In more sophisticated currently available instruments, a special beam splitter is used to produce a rotating beam and a fixed one simultaneously. Up-to-date visible beam rotating lasers are the CLS Accusweep 731 and the AGL Beam Machine. However, the Spectra-Physics 945 Laserlevel GS is considered the world's most advanced level tool.

Invisible beam instruments (GaAs) generate a continuous wave beam and are more compact, lighter and much cheaper than the HeNe instruments. They also use a spinning pentaprism, but unlike visible beam instruments, the speed of rotation is fixed at the ideal speed for the specific detector designed for use with the instrument. Because of their lower power output, the working range is in the region of 200 ms,and all instruments fall into the Class 1 safety category. Few invisible beam instruments can generate vertical planes and none has the facility to generate a sloping plane at a known grade. Visible beam instruments representing in this case the only feasible solution. Current invisible beam rotating lasers are the Spectra Physics EL-1, the Wild LNA2 and the AMA DL150. Fitted with a compensator system, these instruments yield an accuracy of horizontal planes up to ± 2.5 mm per 100 ms.

Rotating beam lasers can be used for all types of surveying work which require the setting up of a horizontal, vertical or sloping reference plane [6] and [7]. This rise in popularity is due to the savings in time, labour and materials as compared with the traditional surveying techniques. They are one-person operated, readings are undertaken at the remote end of the beam, the beam does not sag and can be walked through without damage. Their applications can be split into three broad areas : general site levelling, controlling and monitoring flatness and verticality, and those which machines are controlled by lasers.

General site levelling is the main application of rotating laser instruments. By setting the instrument in the centre of the site, area shaving radii of 300 and 150 ms for visible and invisible instruments,respectively, can be covered. These are large areas for one person to survey and, several operators working from the same rotating source,figure (11), can save a considerable amount of time. Greater accuracy can be achieved if detectors are used to sense the beam on the levelling staff. The dual accuracy facility incorporated in the sensors enables the beam to be sensed typically to within ± 1.5 mm when set on the high sensitivity mode and to within ± 3 mm on the low sensitivity setting.

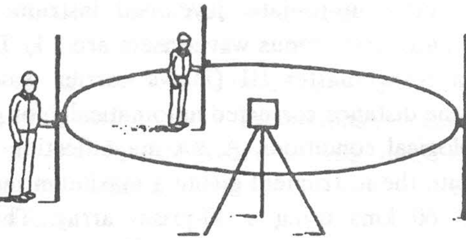

Figure 11. Principle of using several detectors from one source.

Care must be taken, however, to avoid large errors which may occur if two rotating laser systems are being operated within range of each other, since some detectors are capable of sensing the beam from different rotating lasers.

Applications in general site levelling and construction work are numerous : setting form work, placing concrete, fixing structural steel, checking screeding, terracing, controlling excavations, setting out underground drainage, setting out levels for footings, monitoring airport runway construction and marking piling cut-off levels. In conjunction with a detector, rotating lasers are most probably the quickest methods of levelling available. However, they are impractical for use in some fields such as maintaining reference levels for road pavers laying hot asphalt, because of the heat convection effects causing scintillation.

The ability of rotating lasers to produce almost perfectly horizontal or vertical planes makes them ideal for setting out and checking installations where flatness and verticality are critical. The setting out of the internal fittings in a building, such as concrete surfaces,partition walls, sliding doors, electrical light fittings, raised floors and suspended ceilings are all paramount requirements. A dual beam instrument, such as the Spectra Physics 910 or the Laser Beacon 6025,which produces at right angles both, a rotating beam and a fixed beam simultaneously, greatly speeds the fixing of mutually perpendicular members. Once the laser is set up on its side over the baseline and the fixed beam is aligned on a reflective target, the rotating beam automatically defines a plane exactly perpendicular to the baseline. The use of rotating lasers for internal fittings is unfortunately totally neglected in Egypt. Extremely accurate and good-looking finished product may be given and may certainly serve to enhance the reputation of Egyptian installation firms.

In addition to controlling internal fittings, flatness and horizontality can be very accurately checked as in a particular project where a concrete floor was laid at a slope of 1:50 over an area of 4000 m^2. The use of a rotation laser saved half the time as compared with the often awkward conventional plumbing methods, and 10% concrete savings were achieved. Also verticality of high-rise buildings, towers and foundation piles can be better controlled by using vertical laser beams generated by rotating lasers.

Tunnel profiling [6] can also be done using a visible rotating beam laser. The instrument moves along a dark tunnel until the generated vertical plane passes through permanent targets set up at regular distance intervals, thus defining the required profile position. At each profile the shape of the tunnel circumference can be clearly seen and can be recorded on photographic film. Repeating the procedure at intervals of six months or one year enables any movement to be detected by comparing profiles.

A very important area of application for rotating laser systems is monitoring levelling and grading in earthmoving operations in the range of +10% to -10%. One of the best-known systems for controlling earthmoving is the Spectra Physics Laserplane system in which the rotating laser is placed in the centre of the site, and a detector is attached to the earthmover, figure (12). The laser signal is detected and sent to the driver's control box which automatically guides the hydraulic systems of the cutting and levelling edges of the machine to the correct height. A manual system may also be available via a three-light 'high', 'low' or 'on-grade' display. The technique produces a grading accuracy of ± 10 mm and precision as good as ± 6 mm can be achieved. The same system can also be used to survey the ground surface by mounting the detector on a survey vehicle driven over the area, and changes in elevation are recorded on a control box providing terrain surface information. Other well-known laser grading systems are the Blount laser, the Laser Beacon 5000 and the AGL Beam Machine. The gain of utilizing laser to control earthmoving and grading are considerably numerous : 1. They prevent over- or under-cutting, and save time and materials. On a certain project, a fine-grading rate of 5000 m^2 day^{-1} was achieved and eight days' work were saved as well as the cost of a survey team. 2. There is no need to set out stakes. 3. Several scrapers can be controlled simultaneously. 4. The accuracy is within ± 10 mm, and in agricultural grading increases crop yielding. 5. The work can be carried out at night, overcoming any schedule delays. 6. Automatic systems reduce operator fatigue.

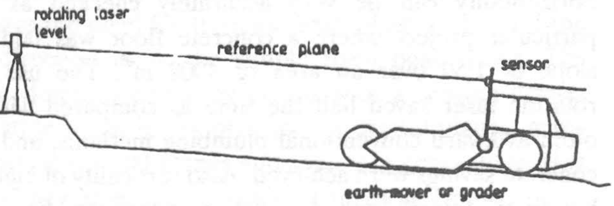

Figure 12. Principle of laser grading control.

The introduction of the Laserplane system particularly to the land reclamation projects in Egypt will certainly allow vast areas to be very accurately controlled with economic savings in time, labour and material. In this aspect, the authors had suggested such laser surveying techniques for the land reclamation at the Noubaria Beet project, and was actually executed with great ease and success.

III- *Distance Measurement Lasers*

Almost all electro-optical instruments in current EDM use modulated infra-red sources, not lasers. This is due to the development of the GaAs infra-red emitting diode which provides a simple and inexpensive means of distance measurement. Despite the predominance of infra-red systems, however, the developing laser rangefinder has become popular in surveying. These timed-pulse [8] distance measuring systems use a neodymium-doped laser source or GaAs lasing diode with infra-red outputs. An advantage is that no reflectors are required. A further use of the HeNe laser in engineering surveying [9] is interferometry where extreme accuracy is demanded over very short ranges up to 50 ms, and it relies on counting the fringes of two interacting laser beams.

The carrier wave used for amplitude modulation is either visible light (HeNe) or infra-red non-lasing GaAs diodes. The latter being extensively used in EDM instruments for its simplicity and cheapness, although it has the disadvantage that the return signal is difficult to detect over ranges greater than 1-2 km. However, with the introduction of the GaAs laser diode, a smaller divergence beam can be transmitted extending the range to 5 kms. On the other hand, HeNe lasers of highly collimated nature can be projected over ranges in excess of 50 kms.

The main factor that limits the accuracy of any EDM measurement and which should be given great care, is the uncertainty of the meteorological conditions. An advantage of a laser carrier wave over conventional infra-red sources, is the spectral purity of the laserlight which suffers low dispersion in air. Instruments with infra-red sources yield EDM accuracy of ± 5 mm ± 5 ppm, while laser instruments achieve better than ± 1 mm ± 1 ppm.

Of the most up-to-date developed instruments using modulation of continuous wave lasers are : 1) The Cubic Precision Rangemaster III (HeNe carrier wave) which displays the distance corrected automatically for prevailing meteorological conditions. A 30x magnification telescope is built into the instrument giving a maximum measurable range of 60 kms using a 30-prism array. The quoted accuracy is ± 5 mm ± 1 ppm. 2) The Kern Mekometer ME 5000 (HeNe carrier wave) is at present, considered to be the most accurate EDM instrument available on a commercial basis,with a quoted accuracy of ± 0.2 mm ± 0.2 ppm and a maximum range of 8000 ms. The first-order precision obtainable makes the Mekometer applicable in monitoring deformations in buildings and dams, and in controlling construction of bridges and tunnels. It is best employed, however, in the precise setting out of positions and components in atomic research plants, in hydro-electric power stations and in critical dimension control and installation of machinery. The ME 5000 is capable of measuring a distance of 8 kms with a mean square error of ± 0.5 mm, compared with 5-10 mm for the same distance using a typical infra-red instrument. 3) Finally, the latest generation of AGA Geotronics laser-based instruments are the IMS 500, 1100 and 1600. The IMS 500 Autotracker can track a moving object with an accuracy of better than 1m at distances of up to 5 km. In the system, measurements of distance and horizontal and vertical angle are continuous and, in effect, the polar vector from the instrument to the target is being continuously measured. When tracking, the instrument is aimed at the target and takes 50 measurements each second, the motion of the prism is followed at speeds of up to 5 ms^{-1} . In surveying, the IMS 500 can be used when a single shore-based station is required for positioning surveying vessels during inshore hydrographic work; also to position moving cranes and barges, and in air traffic control. The IMS 1600 has proved to be popular as a reliable and fast non-contact method for measuring the thickness of iron and steel furnace linings, which is essential for safety purposes in smelting processes.

A greatly advanced mode of measurement is the multi-wavelength measurement. The LDM-2 Terrameter can measure up to 20 kms with a precision of 0.1 ppm without the need for the application of any sort of meteorological observations and corrections along the propagation path. This precision is achieved by simultaneously using two carrier sources,which during propagation, are retarded differently depending on meteorological conditions. The distance is displayed with the first-order temp., press. and humidity removed. The carrier sources are a red HeNe laser and a blue HeCd laser. The ultimate accuracy applications of the Terrameter are in earth strain measurements(earthquake predictions), deformation monitoring and in first-order setting out. This very promising instrument, however, is of a very high production cost.

Another scope of developed EDM instrumentation is the laser rangefinder, based on timed-pulse measurement where the transit time between transmission and detection of a reflected pulse of laser radiation is measured [8]. The pulse is transmitted towards a target which may be uncooperative (backscatter diffuse from hard detail, vegetation)or cooperative (a glass prism of some form). The types of radiation used almost exclusively are the Nd : YAG or GaAs lasers. High intensity pulses are required in order to obtain return signals from diffuse, uncooperative targets. The low divergence of the laser (less than 1 mrad) ensures the detection of return signals at long distances. The Q-switching technique is used to provide a larger than normal population inversion yielding a high energy pulse output. Lasers emitting a high peak power give the longest operating ranges, such as the Nd : YAG rangefinder which measures 10 kms against an uncooperative target. The GaAs laser diode has a similar range, but a reflector must be used,otherwise its range is only 100-200 ms. The main factors contributing to a limitation in range are the atmospheric conditions (in fog, haze and rain the range reduction is extreme) and the sensitivity of the receiver (detectors nowadays are silicon photodiodes capable of detecting a return pulse as small as 10^{-8} W).

Laser time-pulsed or rangefinder instruments representing the latest in a long series of distance measuring systems are the Wild DI 3000, the IBEO Fennel Pulsar and the Cubic Precision Pulsa Ranger. They simultaneously measure both, distances and angles as well as performing profiling and cross-sections, under severe atmospheric conditions with a high degree of precision. Finally, an attractive preposition is the total station system incorporating the FET 2 electronic theodolite and a Pulsar to carry out site surveys (detail surveys) without the need for reflectors.

Laser-based position-fixing rangefinders are also used in hydrographic and offshore surveying operations such as in dredging,positioning of oil rigs, barges and surveying vessels.

Laser application extends beyond surveying to new measurements of wide geophysical significance. The accuracy of measurements of worldwide crustal movements is improved; considering large-scale continental drift and small-scale seismic areas will lead to fuller understanding of earthquake mechanisms.

The impact of laser rangefinders on geodesy and surveying applications is great. Comparing laser techniques with conventional methods, a consuming ratio of at least 5 : 1 could be easily attained. The existing Egyptian triangulation network can be materially strengthened and improved by introducing the "fingerprint" of numerous laser measured lines.

LASER SAFETY

Questionnaire surveys show that many users of laser surveying equipment are only vaguely aware of its safety implications, and that laser safety is not given a high priority on construction sites. The very few accidents arisen from misuse of the low-powered lasers used in surveying should not be taken to imply that the existing safety guidelines are being rigorously followed; it is much more likely to be due either to the intrinsically high standard of manufacture of laser instruments or to the mere sense of wariness of the word laser itself. To ensure excellent safety records, it is vital that the operator of a surveying laser be made aware of its potential safety hazards and how these can be avoided. The following is an attempt to clarify the rather cloudy situation that exists at present.

The main hazards associated with laser instruments are electrical shocks and burns, the ignition of inflammable gases and radiation damage to the skin and to the eye [12], of which the last is undoubtedly the major potential hazard. The high operating voltages of HeNe lasers are well-protected within insulated casings. If the housing is opened while the laser is running, or even up to 30 min after being switched off, a severe shock may occur. In tunnelling or sewer work, sealed terminal batteries should be specified so as to avoid any spark possible of igniting built-up inflammable gases such as methane. As for skin radiation burns, laser surveying instruments are not normally powerful enough to cause any damage.

The factor by which the energy of a high-intensity, collimated beam is concentrated from entering the eye to hitting the retina is enormous. This "optical gain", which is the ratio of the area of the input aperture of the pupil (7 mm max. diam.) to the area of the extremely small focused spot on the retina (20 µm min. diam.), is of the order of 100000 in a visible laser beam. Hence, a modest energy density entering the eye will be turned into a very high one on the sensitive surface of the retina, burning the cells and causing a permanent blind spot. Also the effects of irreversible burn damage to the retina are accumulative,and further compounded by the involuntary movements of the eye causing damage on different parts of the retina. Research has been carried out to assess [10] maximum permissible exposure levels (MPE), i.e. laser radiation level people may endure without suffering adverse effects. The aversion responses of the eye, such as the "blink reflex" which is in the order of 0.25 s, is crucial when assessing the potential danger of a visible laser beam. However, these responses cannot of course protect against invisible beams of sufficient power, such as in pulsed laser rangefinders and some rotating lasers, where damage may occur without the awareness of the observer.

Other factors affecting safety are highly reflective wet surfaces which increase the beam intensity, dusty atmospheres and fine water spray which produce hazardous backscatter of laser light, and direct optical viewing.

The international IEC825 safety guidelines, similar to the British BS4803, specifies a classification system for laser products based on their hazard potential and recommends various engineering and administrative control requirements and precautions :

Class 1 lasers are completely safe for viewing under any circumstances.

Class 2 lasers are of max. output power 1 mW.The blink reflex gives sufficient protection even if optical aids are used to view the beam directly. The beam should not be aimed at personnel. All reflecting surfaces in the vicinity should be removed.

Class 3A lasers have a max. output power of 5 mW. Blink reflex gives sufficient protection only for viewing by unaided eye. Optical viewing is hazardous. In addition to the Class 2 precautions, only trained and qualified personnel should operate. Also warning signs should indicate the location of the whole beam.

Class 3B has an output power 1 to 500 mW. Blink reflex no longer gives sufficient protection. A warning device must be incorporated to operate when the laser is in use. In addition to Classes 2 and 3A precautions,looking directly into the beam by naked eye is hazardous. Optical viewing [11] with unprotected eyes must be totally avoided. Safety eyewear and protective clothing in the laser hazard area are required. They should be rigidly mounted to prevent accidental movement. Periodical Ophthalmic examination for workers is a must. Class 4 lasers are high-powered in excess of 500 mW. They are neither suitable nor safe for any survey or measurement activity.

Laser manufacturers are fully responsible to ensure the appropriate engineering controls such as protective housing, safety interlocks, key control, shutter, laser radiation emission warning, ...etc., and adequate administrative controls concerning maintenance and safe use.

Hazard Assessment

In order to check the safety of a laser, it is necessary to know the radiation wavelength, beam is continuous or pulsed, value of beam hazard potential and safe threshold values. Of these, the first two are obtained from the manufacturer's literature. To evaluate the potential hazard of a beam, its actual irradiance should be compared with safe irradiance figures based on MPE. Thus, if we consider a common type conical beam of maximum power P (mW) and cross-sectional area A (m^2), the irradiance is

$$I = P/A$$

$$\text{but } A = \frac{\pi (d + R\phi)^2}{4}$$

$$\text{therefore } I = \frac{4P \times 1000}{\pi (d + R\phi)^2} \quad W m^{-2}$$

where

d = initial beam diameter (mm)
R = range from the laser (m)
ϕ = sectoral beam divergence (mrad)

As for threshold safety levels, they are expressed in terms of time of eye exposure and provided by the specified MPE in appropriate formulas.

The foregoing information now available, enables the assessment of the safe distance and time for viewing any surveying laser by eye. A general insight and visualized understanding of this assessment is best illustrated by the following example. A Class 3A HeNe laser of max.output power 2 mW, beam diameter 12 mm and divergence angle 0.2 mrad, is 15 ms from a levelling staff. From the irradiance and threshold equations, the following may be assessed:

i) At a distance of 10 ms it is safe to view the beam directly for up to 3.8 s.
ii) It is safe to view the laser directly for a period of 10 s or less from a distance of 19.31 ms
iii) It is safe to view the reflected image of the staff for any length of time up to 7.1 s.

It is strongly recommended here, that the relevant RICS document be thoroughly studied by anyone intending to assess the safety of laser surveying instrument.

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

1. The expensive visible HeNe beam instruments are regarded as prohibited, but will still continue to monopolize the surveying field for the foreseeable future. This is because there is no breakthrough and is not yet possible to provide a cheaper visible semiconductor diode laser beam. A great deal of research and development has yet to be carried out in this aspect. The use of semiconductor lasers in surveying equipment is, however, currently increasing and is representing a different approach to laser design. Without doubt, this type of laser will find many more applications in laser surveying in the near future.
2. Rotating lasers in conjunction with a detector, definitely provide the quickest laser levelling methods yet available. The introduction of Laserplane systems to land reclamation projects in Egypt will control vast areas with savings in time, labour and material.
3. Laser instruments make a great contribution to time and labour savings. A 5 : 1 consuming ratio is normally expected. Human errors are minimized and the output results become more reliable and consistent. This implies us to return to the actual site for ground surface representation instead of applying nonrepresentable cumbersome digital terrain model (DTM) techniques, especially for moderate areas.
4. Atmospheric attenuation seriously affects the laser intensity. The influence of atmospheric refraction on laser radiation is the same as for any other light source. Also air turbulence excurses the laser beam and reduces its coherence thus causing scintillation. Long-range alignment and levelling in a turbulent atmosphere is not recommended at ranges in excess of 150 ms, thus avoiding distortion. For rotating lasers, fluctuating air temperatures on the beam should always be borne in mind. The instrument should be set up to generate its plane as high as is practicable to minimize the influence of the arising systematic errors due to the shimmering effect of warm air rising from the heated ground surface.
5. Care should also be taken to locate the instrument in a position which will avoid surface reflectivity problems producing stray signals.
6. Operation of lasers in adverse weather conditions such as rain, fog or dust should be avoided. A wet target produces a significant amount of specular reflection whereas fog increases backscatter.
7. a) The most susceptible part of the human body to laser radiation is the eye. Thermal damage on the retina is significant, and repeated exposures may produce permanent lesions (blind spot), especially by eye involuntary movements which cause more damage (pain unnecessarily felt) on an area greater than that of the focused image. The "optical gain" seriously ranges from 10^5 to 5×10^5, meaning that a beam intensity of 5 $mWcm^{-2}$ at the cornea becomes 2.5 $KWcm^{-2}$ at the retina. In accordance, the laser beam must not be viewed directly unless the cornea intensity is below the permissible value.
   b) Another factor which has to be appreciated is target reflection. Safety calculations should be based on the assumption that a target is 100% specular and not diffusive.
   c) Some of the pertinent parameters influencing the calculation of threshold levels are wavelength, pulse length, pulse repetition, total energy, beam divergence, power density and retinal image size. The retinal MPE is 1.5×10^{-1} Wcm^{-2} and the corresponding level for corneal irradiance is 3×10^{-7} Wcm^{-2}, meaning that long term exposure must not exceed this value at the outer surface of the eye. An emphasized recommendation is to pursue research for further assessment of the maximum permissible exposure level (MPE).

d) An appropriate word of warning is that any user who wishes to modify a laser by adding a lens to focus the beam to a smaller spot, in so doing introduces further potential hazards and puts the laser into a higher safety category.

e) Safety glasses must provide adequate attenuation of the laser beam incident upon them. They must be worn in all laser operations to filter out specific frequencies characteristic of the laser system in operation and to admit only sufficient light so that the pupil is not unduly large. Direct viewing is, however, not advisable even with safety glasses.

f) Random use of binoculars should be totally prohibited.

g) An area on all sides and at the end of a laser beam should be designated a danger area. h) A very important prohibition is the projection of the laser beam at any non-target objects such as vehicles, houses...etc.

i) Experiments show that C.W. HeNe lasers with identical beam divergence and output powers but different amplifier resonator parameters produce differing amounts of retinal damage. This is due to mode locking where a laser generates a train of very high frequency pulses. Herein lies the danger since its peak power, which is the parameter defining retinal damage, will be greater. Mode locked lasers are a potential hazard which cannot be detected with conventional equipment.

j) Laser radiation encountered by surveyors are visible C.W. HeNe and invisible pulsed infra-red. Guidelines for C.W. invisible radiation emitted by the semiconductor laser diode are lacking. A suitable safety standard guide is urgently needed and should be prepared so as to include a classification system for such devices and in some invisible rotating beam surveying instruments.

k) In construction surveying, the use of Class 1 or Class 2 lasers is much to be preferred if at all possible, being sufficiently powerful to carry out most surveying operations with less safety precautions.

8. The existing Egyptian triangulation network can be quantitatively as well as qualitatively strengthened by the introduction of laser techniques. An evaluation was performed for the Sokkisha Laserplaner LP3A Sno.13088 (with a receiver LPR3A) at the site of the Faculty of Engineering , Alex. Univ., to assure its working capability and efficiency . The result of this evaluation confirms , to a great extent , the above mentioned conclusions and recommendations.

The process by which retinal damage may occur has been explicitly described with the examination of some methods by which this hazard can be reduced, if not totally eliminated. The attitudes of laser users towards safety should be extremely conscientious and not nonexistent. From ongoing discussions the production of an international harmonisation document is well advanced with the intention of unifying all various national standards, and to this end it is essential that users always remain aware that laser is potentially hazardous and must be respectfully treated at all times. The above-mentioned safety precautions tend not to make the laser techniques a mixed blessing tool.

The development of laser instruments in connection with all phases of survey work is considered as one of the epic advances in the science of surveying and geodesy.

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