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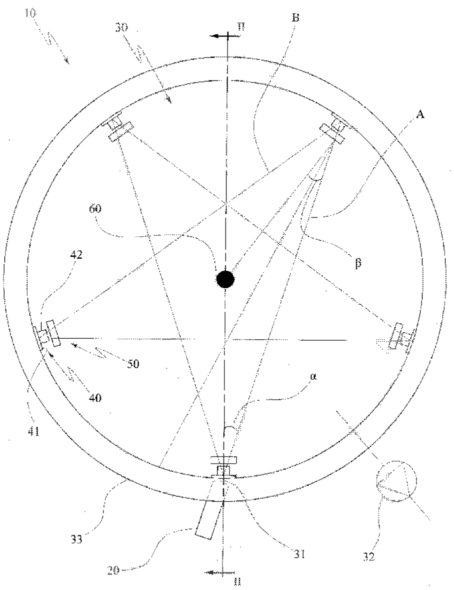

Fig.1

(57) Abstract: The accumulator (10) of light energy comprises: - a source (20) of a light beam; - an accumulation chamber (30) with an entrance (31) through which the laser beam enters the accumulation chamber (30); - a plurality of reflective elements (40) arranged within the accumulation chamber (30) and oriented to reflect the laser beam along a closed reflection path; and deflector means adapted to deflect simultaneously the direction of a reflected light beam (B) from each of the reflective elements (40) towards a point of convergence (O), deflector means comprising a plurality of deflector elements (50), each aligned with a respective reflective element (40) along the respective stretch of reflection path and switchable alternately between a non-reflection configuration with a laser beam incident (A) on each of the reflective elements (40), and a reflection configuration with the laser beam incident (A) on each of the reflective elements (40), wherein each of deflector elements (50) in the reflection configuration is adapted to reflect the incident laser beam (A) by deflecting it from the reflection path towards the point of convergence (O) of reflected light beams (B).

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ACCUMULATOR OF LIGHT ENERGY

Technical Field

The present invention relates to an accumulator of light energy, particularly an accumulator of light energy from a light beam, e.g. a laser beam or a non-coherent light beam.

Background Art

Currently only devices are known definable as "concentrators" of light energy, which use a plurality of laser beams which are made to converge towards a single point, so as to concentrate their energy in that point.

These devices have various industrial applications, in particular in controlled fusion research and in other scientific research fields.

The most powerful laser concentrator is the National Ignition Facility (NIF), a laser-based inertial confinement fusion research installation at the Lawrence Livermore National Laboratory in Livermore, United States.

The NIF uses a plurality of laser generators (in particular number 192) that generate a respective plurality of laser beams which, made to converge at a convergence point, heat the target, e.g., small amounts of hydrogen isotopes, until a nuclear fusion reaction starts. This structure has the main drawback linked to the need of using multiple laser generators and of related energy consumption for the power supply of each single laser generator.

Another drawback is linked to the structural complexity of these devices in terms of overall dimensions and structural realization.

As is known, laser generators are instruments that produce coherent light pulses of extremely short duration, including only a few femto-seconds. (10^{-15} s=1 fs) and with consequent very small dimensions of around tens of nanometers (1nm=10^{-9} m). These pulses are emitted within a range of frequencies called "gain bandwidth" including of around THz (1Tera-Hertz=10^{12}Hz). When the light waves with length λ bounce between the mirrors of a resonant cavity away from each other by an amplitude equal to L, they may interfere constructively or destructively and constructive interference only occurs when standing waves form, i.e., if the following relation is satisfied, wherein

$$L = k^{*}\lambda/2$$

with frequency

$$\nu = kc/2L$$

where k is an integer and the separation between two adjacent frequencies $\Delta\nu$ is equal to

$$\Delta\nu = c/2L$$

where c is the speed of light and substantially $c = 3^{*}10^{8}$ m/s.

These standing waves form a discreet set of frequencies called laser modes (gain bandwidth). In a simple laser, each mode will oscillate independently, like a group of independent lasers and emits slightly different frequencies in a random fashion due to small thermal and electrical variations of the laser materials. In a laser with few oscillating modes, irregular interferences are produced with beats that generate fluctuations in intensity of the laser pulses. In lasers with many thousands of modes these interference effects lead to a nearly constant output intensity: the laser is then said to operate with cw wave or continuously.

If, instead of oscillating independently, there is a certain dependency between the various oscillating modes, due to the introduction in the resonant cavity of the modulation devices, such as gain means, these various modes can interfere constructively with one another, producing intense light pulses: in this case we say the laser is Mode-Locked or phase locked.

In practice, each resonant cavity is delimited longitudinally by a saturable absorber mirror and by an output coupler mirror, with interposition of a gain medium (gain).

The intense light pulses are temporally separated from each other by a time τ given by:

$$\tau=1/\Delta\nu = 2L/c$$

which is the time required for the pulse to cover the resonant cavity, back and forth (between the saturable absorber mirror and the output coupler mirror).

When the pulse reflects on the output coupler mirror, this emits a light pulse outside the laser yielding most of its energy; in turn, the return pulse, after being reflected on the saturable absorber mirror regains the energy transferred through the gain medium. The duration of each light pulse is determined by the number of modes that oscillate in phase induced by a locking system. If N is the number of modes locked with $\Delta\nu$ frequency separation, the bandwidth in locked mode is in general $N^{*}\Delta\nu$. In practice, however, the minimum possible pulse duration is given by:

$$\Delta t = 0.441/(N^{*}\Delta\nu)$$

For example, a typical helium-neon laser (HeNe) has a gain bandwidth ν of about 1.5 GHz and a wavelength of about 2 pm; these pulses are distant from each other by 0.63 μm, while the spectral width, with N=1, is 300 ps.

The energies E_{im} of each pulse vary within a very broad range from a few pJ (pico-Joule=10^{-12}J) to a few tens of J for the mode-locked lasers, up to dozens and hundreds of kJ in the case of super-powerful lasers.

It is observed that if λ_i expresses the distance between two successive pulses, while ν_i expresses the number of pulses emitted by the laser in a second, the effective power W_e expressed by the laser becomes

$$W_e = E_{im}^{*}\, \nu_i = E_{im}^{*} c/\lambda_i$$

Since the efficiency e_f of the lasers does not exceed 15% of its operating power W, we have

$$W_e = e_f^{*} W$$

and from the previous formulas, we obtain

$$E_{im} = e_f^{*} W/\, \nu_i.$$

Many important results have been obtained with mode-locked lasers which are pumped by laser diodes, therefore able to generate output powers of tens of Watts and subpicosecond pulses and also generate trains of pulses with repetition rates of several GHz.

We indicate by W_a the supply power of the laser accumulator which, besides the laser generator, comprises its pumping apparatuses to obtain high laser output powers and also the power of all the reflective apparatuses which partially offset the loss of light reflection (excluding the electro-polarizer powers). If we then indicate by e_i the injection ratio of the actual light power W_i injected by the laser generator, we have that

$$W_i = e_i^{*}\, W_a.$$

Experiments carried out at the NIF have shown e_i to be at most 0.15. It has also been calculated that the coupling coefficient e_a Laser-target (a round metal capsule) is equal to about 0.80.

Therefore the effective light power of the NIF laser to which the surface of the round capsule is subjected, with respect to the supply power W_a, is

$$W_f = e_i^{*} e_a^{*} W_a = 0.12^{*} W_a$$

The NIF laser produces a power density equal to 10^{15} W/cm^2.

It consists of 192 huge laser generators, each with a power density of about $5.2^{*}10^{12}$ W/cm^2 = 5.2 TW/cm^2. Furthermore, the total energy focused on the target for the implosion is 1.8 MJ = $1.8^{*}10^{6}$ J.

Therefore the energy produced by each of the 192 lasers is 9375 J.

Knowing that the target used is a spherical capsule of half a millimeter radius, its surface is substantially equal to $3.14^{*}10^{-2}$ cm^2, consequently the effective power of the laser is equal to $W_f = 10^{15*}3.14^{*}10^{-2} = 3.14^{*}10^{13}$ W and the power of each of 192 NIF laser generators is equal to $1.63^{*}10^{11}$ W, while $W_a = 1.36^{*}10^{12}$ W.

Description of the Invention

The main aim of the present invention is to provide an accumulator of light energy which allows to obtain operating performance, in terms of generated power density, comparable to those of the devices of known type by reducing the number of light energy sources and/or the related operating power, with a consequent reduction in energy consumption.

One object of the present invention is to provide an accumulator of light energy which has reduced overall dimensions and structural complexity compared to the devices of known type.

Another object of the present invention is to provide an accumulator of light energy which allows to overcome the mentioned drawbacks of the prior art within the ambit of a simple, rational, easy and effective to use as well as affordable solution.

The above mentioned objects are achieved by the present accumulator of light energy having the characteristics of claim 1.

Brief Description of the Drawings

Other characteristics and advantages of the present invention will become better evident from the description of a preferred, but not exclusive, embodiment of an accumulator of light energy, illustrated by way of an indicative, but non-limiting, example in the accompanying drawings, wherein:

Figure 1 is a top view of an accumulator of light energy according to the invention in a first embodiment;

Figure 2 is a sectional view according to the section II-II track of Figure 1, wherein the accumulator according to the invention has a first variation of deflector elements;

Figure 3 is an enlargement of a detail of Figure 2;

Figure 4 is a sectional view according to the section II-II track of Figure 1, wherein the accumulator according to the invention has a second variation of deflector elements;

Figure 5 is a view from V of Figure 4;

Figure 6 is a schematic view of the accumulator according to the invention in a second embodiment, dodecahedral in the example;

Figures 7-12 are schematic views of the light beams reflected by the reflective elements within the accumulation chamber of the accumulator of Figure 6;

Figures 13-18 are schematic views representative of the geometry of paths of reflections of a laser beam;

Figure 19 schematically shows an isosceles optical prism with total double reflection;

Figure 20 shows the diagram of an optical prism usable as an input of the system.

Embodiments of the Invention

With particular reference to such illustrations, an accumulator of light energy, in particular of energy from a laser beam, i.e., a light beam of coherent light, monochromatic and concentrated in a highly collimated rectilinear beam has been globally indicated by 10.

According to the invention, the accumulator 10 comprises at least one source of a light beam, e.g. a laser generator 20, which is adapted to emit a laser beam, e.g. of the continuous type or with discreet pulses.

The laser generator 20, e.g., has a supply power W_a substantially between 10^5 W and 10^{10} W.

The accumulator 10 also comprises an accumulation chamber 30 with an entrance 31, e.g., comprising a total-reflection prism transparent to light beams in a cross direction (e.g., from the outside towards the inside of the accumulation chamber 30) and reflecting the light beams in the opposite cross direction (e.g., from the inside towards the outside of the accumulation chamber 30), through which the laser beam emitted by the laser generator 20 enters the accumulation chamber 30.

The accumulator 10 comprises means for forming the vacuum, e.g. a vacuum pump 32 adapted to define a high vacuum inside the accumulation chamber 30.

Within the accumulation chamber 30 are arranged, in a predetermined order, a plurality of reflective elements 40 which are oriented to reflect the laser beam that enters the accumulation chamber 30 along at least a closed reflection path, e.g. along a closed broken line contained inside the accumulation chamber 30.

Preferably, each reflective element 40 comprises a saturable absorber mirror 41.

Furthermore, each reflective element 40 comprises at least one gain medium 42 (gain) which is aligned with the respective saturable absorber mirror 41 along the respective stretch of reflection path and, for example, fixed to it.

Usefully, the accumulator 10 comprises deflector elements 50, adapted to intercept the laser beam along the reflection path and at the same time to deflect the direction of the reflected light beam from each of the reflective elements 40 towards a point of convergence O of the reflected light beams.

The accumulator 10 comprises a target 60, e.g. a capsule made of appropriate material, placed at the point of convergence O (e.g., concentric to it).

A first embodiment, shown in the figures from 1 to 5, shows a two-dimensional or flat accumulator, wherein the laser beam is deflected inside the accumulation chamber 30 along a reflection path lying on a travel plane.

In this case, the reflective elements 40 are positioned at the vertices of an imaginary regular polygon.

To create a closed path, in particular, the angle α which the laser beam forms with the radius of the circumference circumscribed to the regular polygon, imaginary and passing through the injection point of the laser beam in the accumulation chamber 30, must be equal to an integer submultiple of the flat angle, i.e., $\alpha = 180°/k$, with k an integer greater than 2.

In this case, in fact, the laser beam performs some reflections describing identical chords, until it returns to the starting point in which it was injected in the accumulation chamber 30.

In the example shown the imaginary regular polygon is a pentagon (but it cannot be ruled out that it can be a polygon with a number other than five sides) placed inside the accumulation chamber 30.

Such considerations stem from the fact that, as shown schematically in Figures 13-18, the accumulation chamber 30 can be conceived as a "circular billiard table" and the laser generator 20 as a "machine gun" that shoots spherical bullets, on the plane of same, from a point S of its reflection edge, called point of entrance S.

By firing a single bullet, the following three configurations can be achieved:

- a first configuration wherein, if the bullet passes through the center O of the billiard table (figure 13) it reflects on the opposite point called T and again passes through the center continuing repeatedly to cover the diameter through S;
- a second configuration wherein the bullet does not pass through the center but covers a chord of the circle through S which forms an angle α with the diameter. Depending on the value of the angle α, two different cases can be distinguished:
    - a first case wherein α is an integer submultiple of the flat angle, i.e., $\alpha = 180°/k$, with k an integer > 2 (case of Figure 14), then the bullet performs a number of

reflections describing identical chords, until it returns to the starting point S which by constitution is also reflection point;

- a second case wherein, instead, α is not an integer submultiple of the flat angle (case of Figure 15), then the bullet does not return to the starting point S.

In general, the angle at the center β identified by all the chords (or the stretches of the reflection path) is equal to $\beta = 180° - 2\alpha = 180°(k-2)/k = \alpha(k-2)$.

After k reflections, the beam OA performs k rotations with amplitude β, that is, it rotates by a total angle equal to $k\beta = k\alpha(k-2) = 180°\ (k-2)$.

If k is odd (as in the first case shown in Figure 16) k-2 is odd too, therefore the total angle is an odd multiple of 180°, therefore, point A coincides with point T and, in order for the point A to find itself at the starting point S, the bullet must perform other k reflections.

In conclusion, if k is odd, in order for the bullet to find itself at the starting point S, it must perform 2k reflections and the 2k chords it covers form a star the 2k vertices of which identify a regular star polygon inscribed in the circumference.

For example, in the case shown in Figure 16, k is odd and equal to 5, $\alpha = 36°$ and the number of reflections is $n_r = 2k = 10$.

If k is even (second and third case shown in Figures 17 and 18) that is if k = 2p then,

$$\beta = 180° - 2\alpha = 2\alpha(p-1) \text{ and}$$

$$p\beta = 2p\alpha(p-1) = 180°(p-1),$$

therefore we have two possibilities depending on p is even or odd.

If p is odd (case of figure 17), p-1 is even and $p\beta = 180°(p-1)$ is multiple of 360°, and so after p reflections the bullet returns to the starting point S covering p identical chords that form a star the vertices of which are those of a regular star polygon with p sides inscribed in the circumference, as shown in figure 17, wherein this polygon is formed by an odd number of vertices and having a vertex in S does not have a vertex in T (in the example of the figure 16, k=10, p=5 and $\alpha = 18°$).

Alternatively, if p is even (case of figure 18), p-1 is odd then $p\beta = 180°(p-1)$ is an odd multiple of 180°, therefore the bullet after p reflections is at point T opposite S, and must therefore perform further p reflections to return to the starting point S.

In conclusion, the bullet must perform $n_r = k = 2p$ reflections the points of which are the vertices of a regular star polygon symmetrical both with respect to the X axis and to the Y axis and the k chords which it describes form a star with k points, two of which on the X axis and two on the Y axis, as shown in figure 18, e.g., with k=8, p=4 and $\alpha = 22.5°$.

Finally it should be noticed that in the first and third case (Figures 16 and 18) illustrated above, the number of reflections is even and only in the second case (Figure 17) the number of reflections is odd.

Returning to the structure of the accumulator 10, in the example illustrated in Figures 1-4 the accumulation chamber 30 is a cylindrical chamber.

The accumulation chamber 30, in particular, comprises a cylindrical casing 33, e.g. made of a metallic material such as steel.

The cylindrical casing 33, as shown in figures 2, 3 and 4, has a substantially C-shaped (inverted) cross section, wherein e.g. the central stretch has a height substantially equal to 30 cm and at least one of the end portions (the upper one in the illustration) is shaped like a circular crown, wherein the difference between the outer radius and the inner radius is substantially equal to 20 cm.

For example, the cylindrical casing 33 can be made by bending a metal section, e.g. 1 cm thick.

The accumulation chamber 30 also comprises a pair of covers 34, 35, of which a first cover 34 fixed to one of end portions (the upper one in the illustration) of the cylindrical casing 33 and a second cover 35 fixed to the other of the end portions (the lower one in the illustration).

For example, the first cover 34 and/or the cylindrical casing 33 and/or the second cover 35 may have openings which are sealed by removable closure means adapted to the inspection and installation of the internal devices of the accumulation chamber 30.

The accumulation chamber 30 also comprises a support and centering device 36, e.g. fixed to one of the covers 34, 35 at the center of same, adapted to support the target 60 within the accumulation chamber 30 (in suspension with respect to the inner walls of same).

Preferably, the accumulation chamber 30 has an inner diameter substantially equal to 3 meters.

In the example, each saturable absorber mirror 41 is a flat mirror the reflecting surface of which lies on a plane perpendicular to a radius of the accumulation chamber 30 (having a cylindrical shape and therefore circular cross-section) in the reflection point.

The entrance 31 (and the laser generator 20) is, e.g., positioned at one of the reflective elements 40.

The laser generator 20 is configured to introduce a laser beam within the accumulation chamber 30 so that this is inclined by the angle α with respect to a diameter of the accumulation chamber 30 and is directed towards a reflective element 40 not adjacent to the reflective element 40 placed at the entrance 31.

In practice, the saturable absorber mirrors 41, positioned at a regular polygon (pentagon), define a closed reflection path for the laser beam, which will follow a broken line (star shaped in the example); onto each vertex (the reflection point of the laser beam on one of the saturable absorber mirrors 41) of the star-shaped broken line converge an incident portion A of the laser beam and a reflected portion B (which becomes the incident portion A for the next vertex along the reflection path) of the laser beam (symmetrical with respect to the radius of the accumulation chamber 30 which passes through the vertex itself).

The distance b between two non-adjacent vertices (i.e., the path of each incident portion A and of each reflected portion B) is given by the following formula:

$$b = 2R^{*}\cos(\alpha)$$

where R is the inner radius of the accumulation chamber 30.

The deflector means comprise a plurality of deflector elements 50, each aligned with a respective reflective element 40 along the stretch of reflection path in which it is involved.

In practice, each deflector element 50 is interposed between the respective reflective element 40 and the opposite reflective element 40 (i.e. not adjacent to this reflective element 40).

Each deflector element 50 can be switched alternately between a non-reflection configuration at least with the incident portion A of the laser beam directed on the respective reflective element 40 and a reflection configuration at least with the incident portion A of the laser beam directed on the respective reflective element 40.

Practically, each deflector element 50 in the reflection configuration is adapted to reflect the light beam, e.g., the incident portion A of the laser beam, and to deflect the reflected portion B of same with respect to the reflection path towards the point of convergence O.

In the embodiment shown, the point of convergence O coincides with the center of the accumulation chamber 30 (and lies on the plane covered by the laser beam).

In a first variation of the first embodiment, shown in Figures 1 and 2 to 3, each deflector element 50 comprises at least one Pockels cell 51 or equivalent optical element, e.g. an optical crystal of potassium dihydrogen phosphate (KDP) 51.

More in detail, in the present treatise the term KDP is the acronym of potassium dihydrogen phosphate.

The KDP crystal 51, e.g., is connected to power supply means 52 adapted to selectively supply the KDP crystal 51 with an electric field.

In particular, the KDP crystal 51 has the property of rotating the polarization plane by 90° when subjected to intense electric fields.

These crystals are transparent to polarized light in the same polarization plane of the crystal, while they become reflective to the same light if they change polarization due to the effect of an electric field.

In practice, the KDP crystal 51 is configured to be switched, depending on the intensity of the electric power supply field to which it is subjected, between the non-reflection configuration, wherein it is transparent to the incident portion A (and/or to the reflected portion B) of the laser beam allowing this to reach the reflective element 40 (i.e., the saturable absorber mirror 41) placed at the rear of this, and the reflection configuration, wherein the KDP crystal 51 is reflective with respect to the incident portion A of the laser beam.

In particular, if the electric field exceeds a certain threshold value (e.g. positive) the KDP crystal 51 switches from the non-reflection configuration to the reflection configuration, and vice versa in the event of the electric field falling below said threshold value.

For example, each KDP crystal 51 is arranged inside the accumulation chamber 30 so as to intercept at least the incident portion A of the laser beam.

In particular, each KDP crystal 51 is positioned so that the normal to the reflection plane of the KDP crystal 51 (activated by the electric field) at the point of intersection between the reflection plane itself and the incident portion A of the laser beam is coplanar to the covered plane, coincident with the bisector of the angle β, the vertex of which is the point of intersection between the reflection plane of the crystal KDP 51 and the incident portion A of the laser beam and is included between the incident portion A of the laser beam and the radius of the accumulation chamber 30 which passes through such point of intersection between the reflection plane of the KDP crystal 51 and the incident portion A.

In practice, when each KDP crystal 51 is activated (i.e., reflecting the laser beam) by the electric field, it reflects the incident portion A of the laser beam towards the point of convergence O (the reflection angle of each KDP crystal 51 being equal to the incidence angle and equal to β/2).

When the KDP crystal 51 is deactivated (or transparent to the laser beam, e.g., in correspondence of a zero electric field or less than said threshold value) the incident portion A of the laser beam passes through the KDP crystal 51 and reaches the saturable absorber mirror 41 from which it is reflected with a reflection angle equal to the incidence angle, i.e., equal to α.

In particular, when all the KDP crystals 51 are deactivated they are crossed through by the laser beam. As a result, the saturable absorber mirrors 41 allow the laser beam to describe the closed reflection path repeatedly by accumulating more and more light energy.

This way light energy is accumulated along the reflection path, e.g. up to the instant in which the energy dispersed by reflection and other causes offsets the energy introduced by both the laser generator 20 and the gain means 42.

If, once the reflection path has been charged with the maximum energy compatible with same, all the KDP crystals 51 are activated at the same time, these, by polarizing transversely to the polarization planes of the laser beams, reflect the incident portion A on same towards the target 60 placed in the center of the accumulation chamber 30 discharging all the energy previously accumulated in the single time interval, which we shall call simple duration, equal to ΔT_0, wherein ΔT_0 is given by the following relation:

$$\Delta T_0 = b/c = 2R^*\cos(\alpha)/c,$$

where c is the speed of light.

Since each incident portion A (which coincides with the reflected portion B reflected by the previous reflective element 40) to be charged requires a time equal to the simple duration ΔT_0, to charge n incident subsequent portions A a time interval is required equal to $T_n = n^*\Delta T_0$.

By indicating the number of saturable absorber mirrors 41 as n_r, we can write:

$$n=m^*n_r+q$$

where m and q are the quotient and the remainder of the division of n with n_r respectively.

The above relation thus becomes:

$$T_n=n^*\Delta T_0=m^*n_r^*\Delta T_0+q^*\Delta T_0,$$

where m indicates the number of overlaps of light beams on all the n_r sides of the broken line (star-shaped), and the charging time T_c of the accumulator 10 is equal to:

$$T_c=m^*n_r^*\Delta T_0,$$

neglecting $q^{*}\Delta T_0$ because this is a very small percentage compared to T_c and does not therefore affect the results, also because it is always best to take n multiple of n_r.

Finally, the $m*n_r$ factor indicates the gain that can be summed up with N_r, so we have:

$$N_r = m^{*}n_r$$

from which is obtained:

$$T_c = N_r^{*}\Delta T_0$$

and also the efficient energy E_f accumulated in it becomes:

$$E_f = W_f^{*}T_c = N_r^{*}W_f^{*}\Delta T_0 = N_r^{*}e_i^{*}e_a^{*}W_a^{*}\Delta T_0.$$

Because the discharge time must be equal to the simple duration ΔT_0, the actual light power W_e to which the surface of the target 60 is subjected is:

$$W_e = E_a/\Delta T_0 = e_i^{*}e_a^{*}W_a^{*}m^{*}n_r = N_r^{*}W_f.$$

In conclusion, the formulas:

$$T_c = N_r^{*}\Delta T_0;$$

$$W_f = e_i^{*}e_a^{*}W_a;\ W_e = N_r^{*}W_f;\ \text{and}$$

$$E_f = W_f^{*}T_c = N_r^{*}W_f^{*}\Delta T_0$$

express the main magnitudes of the accumulator 10 according to the first embodiment and are dependent on the gain factor N_r, which is proportionate both to n_r, i.e., to the dimensional qualities of the accumulator 10, and to the factor m which depends on the gain means 42, but above all on the reflective capacity R of the saturable absorber mirrors 41.

From the Fabry-Perot parameters, we obtain that the best mirrors can have a reflective power of $R=0.999997=1-3*10^{-7}$.

The simple duration, in the case of the example shown in the illustration wherein α is equal to 18°, is $0.951^{*}10^{-8}$ s = 9.51 ns, which is a time interval compatible with the sensitivity of this type of instrument.

EXAMPLES

Example 1

The laser generator 20 is of the continuous type and the continuous laser beam is injected inside an accumulator 10 according to the first variation of the first embodiment described above.

In the case of a continuous laser generator 20, we can consider as "pulse" the amount of light injected along an incident portion A of the broken reflection line (star-shaped) in the time interval equal to the simple duration ΔT_0.

Considering the injection of n successive pulses, the charging time of the accumulator

10 is a time equal to $n^*\Delta T_0$.

If we indicate as E_0 the effective energy of a single light pulse and as x the reflective power of the mirrors, the residual energy after one, two, three ..., n, ... reflections of the same light pulse becomes E_0^*x, $E_0^*x^2$, $E_0^*x^3$,…, $E_0^*x^n$,…. respectively.

Considering to inject n successive pulses in the circular laser, the first pulse will have accomplished n-1 reflections, the second n-2 and so on, and the last no reflection. As a result the total energy injected into the laser is n^*E_0 while the total residual energy is equal to the sum:

$$E^r_{tot} = E_0+E_0^*x+E_0^*x^2+E_0^*x^3+\ldots+E_0^*x^{n-1} = E_0^*(1+x+x^2+x^3+\ldots+x^{n-1}) = E_0^*(1-x^n)/(1-x)$$

while the total number of reflections of all the pulses is equal to:

$$n_{tot} = 1+2+3+\ldots+n-1=n^*(n+1)/2$$

Finally, we observe that the energy decrease due to the reflections is partially offset by the gain means 42 of the reflective elements 40; this positive contribution is summed up in an ideal reflective power R^{id} better by a few decimal figures than the experimental one, e.g.

$$R^{id}=0.999999999=1-10^{-9}.$$

The reflecting power plays a key role in the efficiency of the accumulator 10, the amount of charge of which depends directly on it.

Furthermore, the percentage of efficient residual energy is equal to:

$$E^r_{\%}= E^r_{Tot}/nE_0= (1-x^n)/[n(1-x)]$$

and because

$$T_c=N_r^*\Delta T_0=n^*\Delta T_0$$

we have:

$$N_r=n$$

Because the effective energy and power are 12% of the supply ones, the implosion energy and power are the residual percentage of 12%. In the table below these residual percentages are arranged as a function of n and x.

The values of n corresponding to 50% of residual percentage for the subsequent values of x are shown in the table below ($E^r_{\%}$ =0.50):

R=x	0.999999	0.9999999	0.99999999	0.999999999	0.9999999999
$n=N_r$	1.6^*10^6	1.6^*10^7	1.6^*10^8	1.6^*10^9	1.6^*10^{10}

Taking into account the value of the reflecting power R^{id}= 0.999999999, we have $N_r=1.6^*10^9$.

This value, being very reliable, will be taken in the following examples.

It also appears that the effective light power W_f given by the effect of reflection dispersion, as mentioned above, decreases by 50%. Therefore:

$$W_f = e_i{}^*e_a{}^*0.50^*W_a = 0.06^*W_a$$

Example 1.1

As a first example we take an accumulator in which the inner radius R of the accumulation chamber is equal to 1.5 m and the power of the laser generator 20 is similar to that of a commercial industrial laser, i.e., W_a=100 KW, furthermore, $\Delta T_0=9.51^*10^{-9}$ s and $N_r=1.6^*10^9$.

This power is significantly lower than that of the individual NIF lasers, the power of which is around 10^{12} W.

We therefore obtain the following:

$$T_c=10^{9*}1.6^*9.51^*10^{-9}=15.216 \text{ s.}$$

$$W_f = 0.12^*0.50^*10^5W = 6^*10\ ^3W$$

$$E_a=W_f{}^*T_c=9.13^*10^4=91300 \text{ J} =0.0913\ ^*10^6 \text{ J} =0.0913 \text{ MJ}$$

$$W_e=N_r{}^*W_f=9.6*10^{12} \text{ W.}$$

Let us suppose that this power is concentrated on the surface of a target 60, i.e., a spherical capsule with a diameter of one millimeter.

Such surface measures 3.14^*10^{-2} cm^2, and the power density per cm^2 becomes equal to:

$$W/cm^2 = (9.6/3.14)^*10^{14}=3.05^*10^{14} \text{ W/cm}^2$$

This value is one third of the power density of the most powerful NIF laser, density which is equal precisely to 10^{15} W/cm^2, while the energy is one-twentieth of the NIF.

These results, obtained with a single laser generator 20 of the reduced power of 100KW are surprising, since they allow to obtain results close to those of a NIF laser generator.

Finally, it is noticed that the charging time of 15.2 s is definitely very high for the purposes of the repeatability of implosions.

Given the reduced dimensions of the instrument, this is due to the high value of the coefficient of gain N_r.

If you decrease the N_r value, both the value of E_f and that of W_e decreases in proportion, but you can consequently increase the residual percentage $E^r{}_{\%}$.

For example, returning to the table above, with R=1-10^9 and $N_r=10^8$, 10^7, 10^6, 10^5, 10^4 the residual percentage becomes $E^r{}_{\%}$ = 0.951; 0.995; 0.9995; 0.99995; 0.999995, i.e. the decrease in the reflections is almost nonexistent.

The functional magnitudes become as in the following table:

N_r	T_c (s)	W_f (W)	W_e (W)	E_f (J)
1.6^*10^9	15.22	6^*10^3	9.6^*10^{12}	9.3^*10^4
10^8	9.51^*10^{-1}	1.14^*10^4	1.14^*10^{12}	1.085^*10^4
10^7	9.51^*10^{-2}	1.19^*10^4	1.19^*10^{11}	1.135^*10^3
10^6	9.51^*10^{-3}	1.199^*10^4	1.199^*10^{10}	1.140^*10^2
10^5	9.51^*10^{-4}	1.1999^*10^4	1.1999^*10^9	11.41
10^4	9.51^*10^{-5}	1.19999^*10^4	1.19999^*10^8	1.141

Only W_f increases when N_r decreases because the residual percentage increases.

The other magnitudes decrease instead proportionally to N_r.

Example 1.2

Now let us show the following basic formulas already previously expressed:

$$\Delta T_0=b/c=2R^*\cos(\alpha)/c$$

$$W_f=e_i^*e_a^*E^r{}_{\%}^*W_a$$

$$T_c=N_r^*\Delta T_0^*W_e=N_r^*W_f$$

$$E_f=W_f^*T_c=N_r^*W_f^*\Delta T_0.$$

If $E^r{}_{\%}=0.50$, $N_r=1.6^*10^9$, W_f is 6% of the supply power W_a of the accumulator 10, ΔT_0 is the dimensional characteristic of the accumulator 10 and increases in proportion to its radius, and consequently T_c and also E_f are proportionate to R. W_e does not depend on the dimensional characteristics of the accumulator 10 either, but only on W_a. Consequently, $E^r{}_{\%}$ being equal, the following rules apply:

- to increase W_e we must increase W_a;
- to increase E_f we must increase W_a or R;
- if we increase W_a, W_e and E_f will also increase; if we increase R, E_f and T_c will also increase.

Finally, N_r being equal, if we increase the number of saturable absorber mirrors 41 (i.e., n_r), m will also decrease in proportion and therefore the energy of the macro-pulses also decreases. This is beneficial to the fact of not damaging the saturable absorber mirrors 41 with pulses which are too powerful.

A very powerful instrument is now to be sized, but with T_c not too high.

To this purpose, we can assume 2R=15 m, $N_r=10^7$ with $E^r{}_{\%}=0.995$ and $W_a=10^{10}$ W, finally $\alpha=18°$.

It follows:

$\Delta T_0 = b/c = 2R^* \cos(\alpha)/c = 4.755^* 10^{-8}$ s

$W_f = 1.194^* 10^9$ W

$T_c = N_r^* \Delta T_0 = 4.755^* 10^{-1}$ s

$W_e = N_r^* W_f = 1.194^* 10^{16}$ W

$E_f = W_f^* T_c = 5.677^* 10^8$ J

Despite the laser generator 20 having an effective power of about 1 GW, i.e., only 6% of the power of the laser generator of the ILIL center in Pisa and of each of the 192 NIF laser generators, the compression energy obtained is over 315 times that of the NIF, and the power is 380 times that of the NIF.

The accumulator 10, as sized according to the Example 1.2, obtains an energy 60480 times greater and a power 729600 times greater than each of the NIF laser generators.

Finally, it should be remembered that, since the charging time is about 5 tenths of a second, the frequency of implosions is about 120 per minute.

Example 2

The laser generator 20 is of the "pulse" type with frequency $\nu = 1/T_0$ and the pulse laser beam is injected inside an accumulator 10 according to the first variation of the first embodiment, described above.

The pulses reflect on the saturable absorber mirrors 41 at exactly the same time and, after describing the reflection path (star-shaped), they are superimposed on the new pulses which continue to be injected into the accumulation chamber 30 by the laser generator 20.

The laser generator 20 can be a Mode-Locked laser, but also an super-powerful pulse laser.

The only difference between a continuous laser and a pulse laser is the laser generator.

All the considerations and all the formulas described above for a continuous laser may be applied to a pulse laser, being careful to replace the light energy charged on each incident portion A (and reflected portion B) of the reflection path with the energy of a pulse.

The energy J_a of each pulse varies within a very wide range from a few pJ to several tens of Joules for the Mode-Locked lasers, to tens and hundreds of kJ for the super-powerful lasers.

It is noticed that if λ expresses the distance between two successive pulses and ν expresses the number of pulses emitted by the laser generator 20 we can write:

$$\lambda = 2R^{*}\cos(\alpha)$$

$$\nu = c/\lambda = 1/T_0$$

The supply power W_a of the laser generator 20 becomes:

$$W_a = J_a^{*}\nu = J_a^{*}c/\lambda$$

Since the efficiency e_i of the laser generator does not exceed 15% of its operating power or supply power W_a, the actual light power W_i becomes:

$$W_i = e_i^{*}W_a = e_i^{*}J_a^{*}\nu = e_i^{*}J_a^{*}c/\lambda$$

Consequently the actual light energy of each pulse J_i is

$$J_i = e_i^{*}J_a$$

and furthermore

$$W_i = J_i^{*}\nu = J_i^{*}c/\lambda = J_i/T_0.$$

Finally, if the laser-target coupling coefficient is indicated by e_a (approximately equal to 0.80), the effective power W_f which hits the target 60 (metal capsule) is given by:

$$W_f = e_a^{*}e_i^{*}W_a = e_a^{*}e_i^{*}J_a^{*}\nu = e_a^{*}e_i^{*}J_a^{*}c/\lambda$$

or given

$$J_f = e_a^{*}J_i = e_a^{*}e_i^{*}J_a$$

we have

$$W_f = e_a^{*}e_i^{*}W_a = e_a^{*}J_i^{*}\nu = J_f^{*}\nu = J_f^{*}/T_0.$$

Finally, taking into account the dispersions caused by the reflections using the coefficient of residual energy $E^{r}_{\%}$ and given

$$J_c = E^{r}_{\%}{}^{*}J_f$$

the following compression power is obtained:

$$W_c = E^{r}_{\%}{}^{*}W_f = J_c^{*}\nu = J_c/T_0$$

Since the laser generator 20 (Mode-Locked) has a frequency equal to $1/T_0$, to charge n successive pulses, a time interval is required of:

$$T_n = n^{*}T_0$$

By then indicating the number of mirrors of the instrument with n_r we can write

$$n = m^{*}n_r + q$$

where m and q are the quotient and the remainder of the division of n with n_r respectively.

Therefore,

$$T_n = n^{*}T_0 = m^{*}n_r^{*}T_0 + q^{*}T_0$$

Where m indicates the number of light pulse superimpositions on each of the n_r sides of the reflection path and the charging time T_c of the instrument is substantially equal to:

$$T_c=m^*n_r^*T_0$$

having neglected the term q^*T_0 because very small by percentage compared to T_c and therefore without effect on the results, also because it is always best to take n multiple of n_r.

Finally, given the factor m^*n_r equal to N_r we obtain:

$$T_c=N_r^*T_0$$

The value of N_r depends on the reflective capacity R of the saturable absorber mirrors 41 and on their resistance to the high energy of light pulses, as has been explained above for the example 1.

Therefore, the effective residual energy percentage $E^r_{\%}$ is calculated in the same way as the continuous laser generator 20.

After N_r elementary pulses, n_r macro pulses are formed, each superimposition of m elementary pulses and each with effective energy $E_{mf} = m^*J_f$.

Therefore, the effective energy E_f becomes:

$$E_f=W_f^*T_c=N_r^*W_f^*T_0=N_r^*J_f$$

while the compression energy of the target 60 is equal to:

$$E_c=N_r^*J_c$$

As regards the discharge time, the n_r macro-pulses, after the concentration reflection, converge simultaneously occupying a circular crown which, in decreasing, propagates towards the center of convergence O on the target 60.

Since the size of the single elementary pulses is a few micrometers and the number of these is very high, around 10^4-10^6, the size of the macro-pulses may be of a few deci-millimeters and so may the size of the circular crown that contains them; it can be assumed, therefore, that the size η of the circular crown is one millimeter. Consequently the discharge time becomes equal to:

$$\Delta t=\eta/c=10^{-3}/3^*10^8=3.33^*10^{-12} \text{ s; and}$$

the ignition power W_g to which the surface of the target 60 is subjected is:

$$W_g=E_c/\Delta t=N_r^*J_c^*c/\eta=3^*10^{11}N_r^*J_c=3^*10^{11}E_c$$

It is observed that η can be different from one millimeter and consequently also

$$\Delta t=n/c\neq 3.33^*10^{-12} \text{ s}$$

We consider that the accumulator 10 has an accumulation chamber 30 with inner radius R and diameter equal to 2R=3m and having as laser generator 20, similar to that of the ILIL Institute of Pisa, the power W_a of which is 10^{10} W slightly lower than one of those of the NIF, therefore $T_0=0.951^*10^{-9}$ s and ν=1.05 GHz.

Given $N_r=10^8$ therefore the coefficient of residual energy $E^r_{\%} = 0.995$, we also take $e_i^* e_a = 0.12$ and consequently $e_i^* e_a^* E^r_{\%} = 0.1194$.

By applying the formulas described above the following values are obtained:

$T_c=N_r^*\Delta T_0=0.951^*10^{-1}$ s

$J_a=W_a^*T_0=9.51$ J

$J_c=0.1194^*J_a=1.1355$ J

$E_c=N_r^*J_c=1.1355^*10^8$ J =113.55 MJ and

$W_g=E_c/\Delta t=3^*10^{11}E_c=3.406^*10^{19}$ W=34.06 EW (EXA-WATT).

The values of the same continuous laser generator are as follows:

$T_c=N_r^*T_0=0.951^*10^{-1}$ s

$W_f=e_i^*e_a^*E^r_{\%}{}^*W_a=1.194^*10^9$ W

$W_e=N_r^*W_f=1.194^*10^{17}$ W

$E_f=W_f^*T_c=1.1355^*10^8$ J.

It should be noticed that T_c is the same in both cases and that also E_c and W_f are equal, while W_g is greater than W_e because Δt is less than ΔT_0.

Considering that the laser generator 20 has the same power as the one of the ILIL center in Pisa, the most powerful of Italy, and of just one of the 192 lasers of the NIF, the compression energy obtained by using the accumulator 10 is over 63 times that of the NIF and the power is 10^6 times that of the NIF.

Finally, because the charge time is about one tenth of a second, the frequency of the implosions is about 600 per minute, and therefore fairly high.

In a second variation of the first embodiment of the invention, shown in the Figures from 4 to 5, each deflector element 50 comprises at least one mirror 53, e.g. flat, inclined with respect to the reflection plane of the reflective element 40 (i.e. to the reflection plane of the saturable absorber mirror 41) and associated movable inside the accumulation chamber 30, alternatively between the non-reflection configuration, wherein the mirror 53 is misaligned with respect to the direction of the incident portion A of the laser beam along the reflection path allowing the same to reach the reflective element 40 (i.e. the saturable absorber mirror 41) placed at the rear, and the reflection configuration, wherein the mirror 53 is aligned with the direction of the incident portion A along the reflection path and deflects, by reflection, the latter in such a way that the reflected portion B by the mirror 53 is directed towards the point of convergence O.

In practice, the mirror 53 is positioned so that, when it is in the reflection configuration, the normal to the reflection plane of the mirror 53 at the point of intersection between the reflection plane itself and the incident portion A of the laser beam is coplanar to the covered plane and coincident with the bisector of the angle β, the vertex of which is the point of intersection between the reflection plane of the mirror 53 and the incident portion A of the laser beam and is included between the incident portion A of the laser beam and the radius of the accumulation chamber 30 which passes through such point of intersection between the reflection plane of the mirror 53 and the incident portion A.

In practice, when each mirror 53 is in the reflection configuration it reflects the incident portion A of the laser beam towards the point of convergence O (being the reflection angle of each mirror 53 equal to the angle of incidence and equal to β/2).

When the mirror 53 is in the non-reflection configuration the incident portion A of the laser beam reaches directly the saturable absorber mirror 41 from which it is reflected with an angle of reflection equal to the angle of incidence, i.e. equal to α.

In particular, when all the mirrors 53 are in the non-reflection configuration they do not deflect the laser beam.

As a result, the saturable absorber mirrors 41 allow the laser beam to describe the closed reflection path repeatedly by accumulating more and more light energy.

This way light energy is accumulated along the reflection path, e.g. up to the instant in which the energy dispersed by reflection and other causes offsets the energy introduced by both the laser generator 20 and the gain means 42.

If, after charging the reflection path with the maximum energy compatible with same, all the mirrors 53 are brought to the reflection configuration at the same time, these reflect the incident portion A on same towards the target 60 located in the center of the accumulation chamber 30 discharging all the previously accumulated energy in the single time interval (simple duration) equal to ΔT_0, wherein ΔT_0 is given by the following relation:

$$\Delta T_0 = b/c = 2R^* \cos(\alpha)/c.$$

The simple duration, in the case of the example shown in the illustration wherein α is equal to 18°, is $0.951 * 10^{-8}$ s = 9.51 ns which is a time interval compatible with the sensitivity of this type of instrument.

A possible alternative embodiment of the second variation described above is shown in Figures 4-5 and provides that the mirror 53 be associated in a rotatable manner inside the accumulation chamber 30.

In particular, the cylindrical casing 33 is adapted to support in rotation, for each deflector element 50, a shaft 54 fitted in the cylindrical casing 33 (e.g. radially) at a point near (but not coincident) to a fixing point of the reflective element 40 to the cylindrical casing 33 and supported by appropriate revolving members.

In particular, the shaft 54has an axis of rotation aligned in plan with the normal median to the reflection plane of the saturable absorber mirror 41.

The mirror 53 is fixed to the portion of the shaft 54 arranged inside the accumulation chamber 30 in an area moved towards the center of the accumulation chamber 30 with respect to the reflective element 40 and, e.g., locked in rotation together with the shaft itself.

The portion of the shaft 54 located externally to the accumulation chamber 30 is connected, by means of suitable motion transmission members, to an electric motor 56 configured to actuate the shaft 54 in rotation and then the mirror 53.

The transmission members, for example, comprise gears, of which at least one driving gear 551 associated with the electric motor 56 and at least one driven gear 552 associated with the outer portion of the shaft 54, and a bearing ring 553 with crown gears interposed between them.

In practice, the mirror 53, during rotation of the shaft 54, is adapted to be located in various angular positions, of which at least one in which the mirror 53 is aligned (with respect to the direction of the incident portion A of the laser beam) with the reflective element 40, adapted to define the reflection configuration described above, and at least one in which the mirror 53 is misaligned (with respect to the direction of the incident portion A of the laser beam) with the reflective element 40, adapted to define the non-reflection configuration of the mirror 53 itself.

In the embodiment shown the mirror 53 is supported by a wheel 57 keyed on the inner portion of the shaft 54 and defines a discreet radial enlargement of the same.

At each revolution of the wheel 57 the mirror 53 finds itself in at least one reflection configuration interspersed with a plurality of non-reflection configurations.

It cannot however be ruled out that the number of mirrors 53 which can selectively be located in front of each reflective element 40 may be in a number different to one.

The accumulator 10 also comprises synchronization means (not shown) adapted to synchronize the rotation of the electric motor 56 and centering means, so that the mirrors 53 are located all simultaneously at the same time in the respective reflection and non-reflection positions.

This way all the mirrors 53 rotate in perfect synchrony with one another and with the same angular velocity ω. If we indicate by r the radius of the driven gear 552, by r_{uo} the outer radius of the mirror 53, by R_a the radius of the bearing ring 553, by $p=R_a/r$ the number of revolutions accomplished by the wheel 57 (and therefore the mirror 53) for each revolution of the bearing ring 553, by δ the angle at center (wherein the center is the axis of rotation of the shaft 54) which comprises the mirror 53, by Ω the angular velocity of the bearing ring 553, and finally by T_ω and T_Ω the period of rotation of the wheel 57 (or of the mirror 53) and of the bearing ring 553 respectively, we can determine the angular velocity Ω which the bearing ring 553 must have so that the charging time of the accumulator 10 (wherein the laser beam covers the closed reflection path) is a certain time T_c and the next discharge time is equal to the simple duration ΔT_0.

Since the bearing ring 553 causes the wheel 57 to rotate, between the velocities and the rotation periods the following relations exist:

$$\omega = p^*\Omega$$

$$T_\Omega = p^*T_\omega = (R_a/r)^*T_\omega$$

Furthermore, the rotation of the mirror 53 (subtended to the angle δ) has a duration equal to ΔT_0, while the rotation of 2π-δ must take place in the time T_c.

Therefore, being $T_c=N_r{}^*\Delta T_0$, it results that $\Delta T_0+T_c=T_\omega$,, from which $(N_r+1)^*\ \Delta T_0=T_\omega$.

We obtain that:

$$T_\omega=(N_r+1)^*\ \Delta T_0=(N_r+1)^*2R^*\cos(\alpha)/c=(N_r+1)^*2R^*\cos(\alpha)/c$$

$$T_\Omega=p^*T_\omega=(R_a/r)^*T_\omega=(N_r+1)^*2R_a{}^*R\ ^*\cos(\alpha)/(r^*c)$$

$$\delta=\omega^*\Delta T_0=(2\pi/T_\omega)\ ^*\Delta T_0=2^*\pi/(N_r+1)$$

Finally, the radius of the driving gear 551 being r_M, the rotation speed of the electric motor 56 becomes:

$$\Omega_M=(R_a/r_M)^*\Omega$$

Example 3

The laser generator 20 is of the continuous type and the continuous laser beam is injected inside an accumulator 10 according to the second variation, described above, of the first embodiment.

An initial check can be made to make sure the values of rotation periods of the mirror 53 are technically feasible.

Assuming $N_r=10^7$; $R_a=1.55$ m, r=0.005 m, $r_m=0.1$ m, ρ=310, $\Delta T_0=9.51^*10^{-9}$ and $r_{uo}=0.10$ m we obtain:

$T_\omega=(10^7+1)^*9.51^*10^{-9}=0.0951$ s

$\omega=2\pi/T_\omega=66.069$ rev/s

$T_\Omega=310^*0.0951=29.48$ s

$\Omega = 2\pi/T_\Omega = 0.213$ rev/s

$\delta = \omega^* \Delta T_0 = 66.069\ ^*9.51^*10^{-9} = 6.283^*10^{-7}$ rad

$d = \delta^* r_{uo} = 6.28^*10^{-8}$ m and

$\Omega_M = (R_a/r_M)^*\ \Omega = 3.3$ rev/s.

These figures show that, while the angular velocities are normal, the size of the mirror 53 instead is equal to 62.8 nm and is therefore virtually impossible to make.

To overcome such drawback, some considerations have been made which are mentioned below.

Since the following relations are valid:

$\delta = \omega^* \Delta T_0 = 2^*\pi/(N_r + 1)$ and

$d = \delta^* r_{uo} = 2^*\pi^* r_{uo}/(N_r + 1)$,

to obtain values of d greater than those obtained by applying the formula, we have to reduce N_r and increase r_{uo}.

However, if we decrease N_r both the energy and power decrease proportionately.

With the data of the accumulator 10 used for the example 1, the values of d are calculated corresponding to the successive values of N_r in the following table:

N_r	1.6^*10^9	10^8	10^7	10^6	10^5	10^4
d	3.9^*10^{-10}	6.28^*10^{-9}	6.28^*10^{-8}	6.28^*10^{-7}	6.28^*10^{-6}	6.28^*10^{-5}

Even the highest value of the tooth which is 62.8 μm does not have the correct size of a mirror 53.

Furthermore for $N_r = 10^4$, even taking a very powerful laser generator 20 with $W_a = 10^{10}$ W, the energy E_f is 1.141^*10^5 J, and therefore less than the ignition energy which is 1.8^*10^6 J.

In conclusion, the mechanical solution by means of the second variation of the first embodiment shows itself to be a good solution for the functionality of the instrument.

If the temporal dimension of the mirror 53 is equal to:

$$\Delta T_d = N^d_r{}^* \Delta T_0 \text{ and}$$

$$T_{cd} = N^c_r{}^* \Delta T_0,$$

where N^d_r and N^c_r indicate the number of durations of the mirror 53 and also of the new charge time.

Because $T_\omega = (N_r + 1)^* \Delta T_0 = T_{cd} + \Delta T_d = (N^d_r + N^c_r)^* \Delta T_0$ we have:

$$(N^d_r + N^c_r) = N_r + 1$$

and the new charge time T_{cd} becomes

$$T_{cd}= T_{\omega}-\Delta T_d = (N_r - N^d_r +1)^* \Delta T_0$$

and the angle at the centre of the tooth δ_d corresponding to ΔT_d is therefore

$$\delta_d = \omega^* \Delta T_d = 2^* \pi N^d_r/(N_r+1)$$

Consequently, the angular width D of the mirror becomes:

$$D=\delta_d{}^* r_{uo} = 2^* N^d_r{}^* \pi^* r_{uo}/(N_r+1).$$

Taking for example $N_r=10^7$, $N^d_r=10^6$ and $r_{uo}= 0.10$ we obtain

$\delta_d = 0.628$ rad $=36°$

$D = 0.0628$ m $= 6.28$ cm

The value D=6.28 cm seems compatible with the dimension of a reflecting mirror.

On the basis of the new initial parameters, the relations shown below

$$T_c = N_r{}^* \Delta T_0$$

$$W_e = N_r{}^* W_f$$

$$E_f = W_f{}^* T_c = N_r{}^* W_f{}^* \Delta T_0$$

become

$$\Delta T_d = N^d_r{}^* \Delta T_0$$

$$T_{cd} = N^c_r{}^* \Delta T_0$$

respectively, where to N^c_r corresponds a new residual percentage $E^d_{\%}$, and so:

$$W^d_f = e_i{}^* e_a{}^* E^d_{\%}{}^* W_a$$

$$E^d_f = W^d_f{}^* T_{cd} = W^d_f{}^* N^c_r{}^* \Delta T_0$$

$$W^d_e = E^d_f / \Delta T_0 = N^c_r{}^* W^d_f$$

In practice, the new formulas are obtained from the old ones replacing N_r with N^c_r.

With the parameters set by the accumulator 10 we obtain:

$\Delta T_d = N^d_r{}^* \Delta T_0$ with $N^d_r = 10^6$ consequently

$N^c_r = 9^* 10^6$ and $E^d_{\%} = 0.9995$ and furthermore,

$W^d_f = 1.1994^* 10^9$ W

and because $\Delta T_0 = b/c = 2R^* \cos(\alpha)/c = 4.755^* 10^{-9}$ s we have

$T_{cd} = N^c_r{}^* \Delta T_0 = 4.279^* 10^{-2}$ s,

$W^d_e = N^c_r{}^* W^d_f = 1.079^* 10^{16}$ W

$E^d_f = W^d_f{}^* T_{cd} = 5.132^* 10^7$ J.

As was to be expected, there has been a slight increase in effective power (W_f) and a 10% drop in the other parameters, proportionate to the drop of N_r.

If the laser generator 20 emits a continuous beam, the shorter discharge time can only be the simple duration ΔT_0 and the consequent power is given by:

$$W^d_f = e_i{}^* e_a{}^* E^d_{\%}{}^* W_a$$

$$E^d_f = W^d_f{}^* T_{cd} = W^d_f{}^* N^c_r{}^* \Delta T_0$$

$$W^d_e = E^d_f / \Delta T_0 = N^c_r{}^* W^d_f$$

In the case, instead, of a laser generator 20 being of the pulse type emitted with a frequency equal to a duration period ΔT_0, the discharge takes place with a very short pulse to the advantage of power.

Irrespective of the first and second variation of the first previously described embodiment, alternative embodiments cannot be ruled out wherein the accumulation chamber 30 has baffle means operatively connected to each of the reflective elements 40 for the deviation of pulses which may collide during their propagation inside the accumulation chamber itself.

More in detail, the star polygons with n_r vertices, defined by the reflection path of the light pulses, have the sides ℓ which intersect each other inside the circumscribed circumference of the star polygon forming regular polygons with n_r vertices, called intersection polygons, as can be seen from figures 16, 17, 18.

The pulses, in covering the reflection path defined by the regular polygon, can encounter at the vertices of the intersection polygon, thereby deviating from their path along the sides of the star polygon.

In such case the two pulses, after collision, are absorbed by the wall of the accumulation chamber 30 and the accumulator 10 stops functioning.

P being the length of the perimeter of the star polygon with side ℓ and λ the distance between the two subsequent pulses emitted by the laser source 20, it can occur that two pulses collide at one of the vertices of the intersection polygon.

To overcome this drawback, the baffle means permit moving the position of the two vertices of a same side from the penta-star polygon plane, called lying plane, leaving the sides unchanged.

This is achieved, e.g. in the case of the penta-star polygon, by maintaining unchanged the position of the three vertices on the lying plane, and increasing, by means of the baffle means, by an angle β the angle α of each vertex of the penta-star polygon of an entity e.g. between 3° and 5°.

In this treatise, the angle β is defined as anti-incidence angle.

More in detail, by means of the movement of the baffle means, two vertices of the penta-star polygon depart from the lying plane so the five vertices belong to a spherical surface the center of which is called center of the quasi-polyhedron.

A closed broken line is thus obtained which forms a three-dimensional star pentagon with all the sides identical which do not intersect each other two by two non-consecutive and with all the angles of the vertices identical to one another.

Such three-dimensional star pentagon is definable as a regular askew star quasi-polyhedron with anti-incidence angle β.

Defining $P_i(x_i, y_i, z_i)$ with $i=1,2,..,n_r$ as the vertices of the regular askew star quasi-polyhedron β (more simply called quasi-β-polyhedron) and $\theta = \alpha+\beta$ as the angle defined in P_{i+1} the following relations must be verified:

$$\begin{cases} (x_i * x_{i+1}) + (y_i * y_{i+1}) + (z_i * z_{i+1}) = R^2 - \dfrac{\ell^2}{2} \\ x_i^2 + y_i^2 + z_i^2 = R^2, \qquad i = 1, 2, \ldots, n_r \\ \theta = \alpha+\beta \end{cases}$$

where $n_r + 1$ is substituted with 1.

Taking $P_1 = (-\ell/2, 0, 0)$ and $P_2\,(\ell/2, 0, 0)$ and P_3 belonging to the second quadrant of the plane XY, i.e., $P_3\,(x_3, y_3, 0)$, the above introduced system for i=2 admits a solution which substituted with i=3 permits its solution and so on.

By using the deflector means which introduce the anti-incidence angle β the problem is therefore solved tied to the internal interferences generated between pulses that collide in the same instant at the vertices of the intersection polygon and which therefore compromise the correct operation of the accumulator 10.

Furthermore, depending on the entity of the anti-incidence angle β, the vertices of the quasi-β-polyhedron are almost uniformly distributed on the sphere.

In other words, in the case of a reflection path of the type of a regular star polygon, a quasi-polyhedron is obtained well distributed on the sphere formed by just one closed broken line and, advantageously, the broken line itself can be charged by just one injector laser generator 20.

A second embodiment, shown in the figures from 6 to 11, shows a three-dimensional accumulator 10, wherein the laser beam is deviated inside the accumulation chamber 30 along a three-dimensional reflection path.

One of the main characteristics that the three-dimensional accumulator 10 must have is to hit the target 60 (spherical capsule) located within the accumulation chamber 30, with a homogeneous distribution of the laser pulses on the spherical surface.

To obtain this homogeneity the pulses must start simultaneously from the vertices of a regular polyhedron, such as e.g. a tetrahedron, a cube, an octahedron, a dodecahedron, and an icosahedron.

Advantageously, the reflective elements 40 are positioned at the vertices of an imaginary regular polyhedron, in the example the dodecahedron, placed inside the accumulation chamber 30.

In the illustrated example, the accumulation chamber 30 is a spherical chamber (not shown), e.g. made from metal shells (steel), the inner (spherical) surface of which inscribes the imaginary dodecahedron above.

In the regular dodecahedron, if each segment joining two vertices not belonging to the same face is defined as a diagonal line, from each vertex depart 10 diagonal lines, so the total number of the diagonal lines is equal to 100.

These diagonal lines have three different lengths, i.e. there are three types of diagonal lines, of which a first type defined as short diagonal lines, a second type defined as medium diagonal lines and a third type defined as central diagonal lines.

From each vertex of the dodecahedron depart six short diagonal lines, three medium diagonal lines and one central diagonal line.

Through each vertex of the dodecahedron, furthermore, pass three symmetry planes to which the three medium diagonal lines belong.

If the dodecahedron is arranged so the two parallel faces (called bases) are on horizontal planes and from each vertex of a base, the two medium diagonal lines are traced that join the vertices of the opposite base, a closed broken line is obtained (hourglass shaped, as shown in Figure 12), formed of ten sides all identical to the medium diagonal lines.

If we indicate by R the radius of the sphere circumscribed to the dodecahedron which has a corner with length ℓ and we call d the medium diagonal line, we have that:

$$d = R^{*}\sqrt{3}^{*}(\sqrt{5}+1)/3 = \ell^{*}(3+\sqrt{5})/2$$

$$R = d^{*}\sqrt{3}^{*}(\sqrt{5}-1)/4 = \ell^{*}\sqrt{3}^{*}(\sqrt{5}-1)/4$$

$$\ell = d^{*}(3-\sqrt{5})/2 = R^{*}\sqrt{3}^{*}(\sqrt{5}-1)/3.$$

Considering the dodecahedron arranged as described above, the remaining ten lateral vertices are above two horizontal planes which are symmetrical with respect to the center of the dodecahedron and form two regular pentagons, wherein the imaginary segments that join each vertex to the opposite non-adjacent vertices define ten sides identical to the medium diagonal lines d.

In practice, for each regular pentagon a star-shaped broken line is defined (similar to that of the first embodiment), as shown in Figures 7-9.

Furthermore, it can be observed that the two star-shaped broken lines and the hourglass-shaped broken line are each made up of segments identical the one to the other and identical to the medium diagonal lines d, precisely five sides for each star-shaped broken line and ten sides for each hourglass-shaped broken line.

Inside the accumulation chamber 30, e.g. at the center of the sphere, the target 60 is supported (e.g. by support means not shown adapted to keep the target 60 in suspension at the center of the accumulation chamber 30).

At each vertex of each star-shaped broken line and of the hourglass-shaped broken line a reflective element 40 and a respective deflector element 50 are placed, as described above for the first embodiment.

In the example, each saturable absorber mirror 41 is a flat mirror, the reflection (flat) surface of which lies on a plane perpendicular to a radius of the (spherical) accumulation chamber 30.

A plurality of entrances 31 and a respective plurality of laser generators 20, as previously described, are positioned e.g. at respective reflective elements 40, of which e.g. a first reflective element 40 located at a vertex belonging to one of the star-shaped broken lines, a second reflective element 40 located at a vertex belonging to the other of the star-shaped broken lines, a third and a fourth (opposite) reflective element 40 located at a respective vertex belonging to the hourglass-shaped broken line.

A laser generator 20 is arranged, in particular, in each of the two star-shaped broken lines and other two laser generators 20 on opposite vertices of a same central diameter of the hourglass-shaped broken line and so that the laser beams emitted from these last two laser generators 20 cover the respective stretch of the hourglass-shaped broken line in the same travel direction.

Each laser generator 20 is configured to introduce a (continuous or pulsed) laser beam inside the accumulation chamber 30 so that this is inclined by an angle α with respect to a radius of the accumulation chamber 30 and is directed towards a reflective element 40 not adjacent to the reflective element 40 placed at the entrance 31, covering a stretch of the related (star-shaped or hourglass-shaped) broken line it is involved in.

These four laser generators 20 are simultaneous to one another and, in the event of being of the pulse type, they can be configured so as to emit a pulse after each time interval equal to the simple duration ΔT_0 and so:

$$\Delta T_0 = 2^* d/c = 2^* d/(3^* 10^8)\ s$$

In practice, the saturable absorber mirrors 41, placed at the vertices of the regular polyhedron (dodecahedron), define a closed reflection path for each laser beam, which will follow the related broken line.

Onto each vertex (reflection point of the laser beam on one of the saturable absorber mirrors 41) converge an incident portion A of the laser beam and a reflected portion B of the laser beam (symmetrical with respect to the radius of the accumulation chamber 30 which passes through the vertex itself).

The deflector means comprise a plurality of deflector elements 50, as described for the first embodiment, each aligned with a respective reflective element 40 along the stretch of reflection path it is involved in.

In practice, each deflector element 50 is placed between the respective reflective element 40 and the opposite reflective element 40 and aligned with respect to a stretch of the (star-shaped or hourglass-shaped) broken line with the related reflective element 40.

Each deflector element 50 is switchable alternatively between a non-reflection configuration, at least with the incident portion A of the laser beam directed onto the respective reflective element 40, and a reflection configuration, at least with the incident portion A of the laser beam directed onto the respective reflective element 40.

Practically, each deflector element 50 in the reflection configuration is adapted to reflect the light beam, e.g., the incident portion A of the laser beam, and to deflect the reflected portion B of same with respect to the reflection path towards a point of convergence O.

In the embodiment shown, the point of convergence O coincides with the center of the (spherical) accumulation chamber 30.

In the case of the three-dimensional accumulator 10 as well, the deflector element 50 can be of the type shown in the first variation of the first embodiment, i.e., comprise Pockels cells comprising KDP crystals 51, or of the type shown in the second variation of the first embodiment, i.e., comprise a movable/revolving mirror 53.

For a detailed description of the deflector elements 50, see the description given previously.

Similarly to the first embodiment, also for the second embodiment alternative embodiments cannot be ruled out wherein the accumulation chamber 30 comprises the baffle means described previously to avoid the formation of internal interference between pulses that encounter in the vertices of the intersection polygon.

More in detail, in the case of the regular dodecahedron formed of two central pentagons and the hourglass, the baffle means operate on the angles defined in correspondence of at least one vertex of each star-shaped broken line and of the hourglass-shaped broken line varying their relative amplitudes.

In other words, the two pentagons and the hourglass are replaced by quasi-α-polyhedrons so as to eliminate all the intersections of the sides defining the regular dodecahedron.

With the configuration of the three-dimensional accumulator 10 described above, two identical two-dimensional accumulators 10 are in practice obtained (defining a respective reflection path along the respective star-shaped broken lines), while along the hourglass-shaped broken line two iso-oriented laser beams are made to accumulate, wherein after five laser pulses (or in any case after every period of time equal to five times the simple duration ΔT_0) there is a pulse above each one of its medium diagonal lines d, as on the segments, of the same length as the medium diagonal lines, of the star-shaped broken line.

This way the four laser generators 20 charge the twenty medium diagonal lines of the three-dimensional accumulator 10 (after each period of time equal to five times the simple duration ΔT0) forming twenty pulses that at any instant are located on the vertices of a dodecahedron, or at the twenty saturable absorber mirrors 41 (or deflector elements 50).

For example, if the four laser generators 20 of the accumulator 10 are considered, according to the second embodiment, the compression energy and the ignition power will be four times greater than those previously described for the two-dimensional accumulator 10 shown in the first embodiment and, in particular:

$E_c = 4^* 108.5$ MJ $= 434$ MJ

$W_g = 4^* 32.558$ EW (EXA-WATT) $= 1.30^* 10^{20}$ W.

Such values are decidedly greater than those needed for the implosion of target 60 made up of a spherical capsule with a diameter of 1 mm containing deuterium and tritium, furthermore they have enough energy and power to obtain the fusion of the nuclei of boron 11 and hydrogen.

Consequently, if we assume that the three-dimensional accumulator 10 has the medium diagonal line d with length identical to the length of the distance b between two non-adjacent vertices of the two-directional accumulator 10 (shown in the first embodiment), i.e., $b=3^*\cos(18°)$, we obtain that:

$d = R^{*}\sqrt{3}^{*}(\sqrt{5}+1)/3 = 3^{*}\cos(18°)$, hence R=1.528 m.

Furthermore, the power density per cm^2 on the target 60, i.e., a spherical capsule with a diameter of one millimeter, is substantially equal to:

$W/cm^2 = 1.30^{*}10^{20}/3.14^{*}10^{-2} = 4.138^{*}10^{21}\ W/cm^2$

which is five million times greater than that used in the NIF to obtain the implosion of deuterium and tritium.

In these calculations, account has been taken of the inertias due to the instruments.

The value of $N_r=10^8$ which depends on the high experimental value of the reflective power of the saturable absorber mirrors 41 could have a few orders of magnitude more while always guaranteeing excellent results.

To overcome the drawback of the high power of the pulses which could damage the saturable absorber mirrors 41, the pulses themselves are distributed evenly on an adequate surface of the apparatuses, until the last reflection, and finally are made to converge on the target 60.

Moreover, the inner surface of the appliance being a spherical surface, the shock wave from the implosion of the target 60 is reflected converging in the center of the sphere, with the possibility of producing the implosion of a new target 60 specially located in the center of the accumulation chamber 30.

Advantageously, subsequent implosions of a plurality of targets 60 are then obtained in a natural and automatic manner without using a suitable implosion laser.

Returning to the issue of the reflecting apparatuses placed at the vertices of the polygon, the reflecting apparatuses used in the previous treatise are substantially of two types and precisely: simply reflecting apparatuses and entrance reflecting apparatus.

The simply reflecting apparatuses each consist of a highly-reflecting mirror which generally speaking can be a simple highly-reflecting plate or an (isosceles) prism with total double reflection with angles at the base ϕ and at the vertex β, as described in Figure 19. These prisms, or the reflecting plates, are located in the vertices of the star polygon of the appliance as described in figure 1, excluding the vertex S where the injector Laser assembly is arranged.

The graph in Figure 19 permits determining the formulas between the refraction and reflection angles of an isosceles prism with angles at the base ϕ and angle at the vertex β. Let l be the limit angle of the prism and

$$n_{1,2} = \text{sen}(i)/\text{sen}(r) > 1$$

the refraction index relating to same.

Let the incident radius i in the point A of the base a have an incidence angle i< l, and let

$$r = \arcsen[\sen(i)/n_{i,2}] < l$$

be the angle of refraction.

The refracted angle r encounters the face b of the prism in its point B, the angle γ of which with the normal n_B in B is also the external angle of the triangle BHA, which gives

$$\gamma = \phi + r > l.$$

Because $\gamma > l$ in B we have total reflection and the reflected beam encounters the face c of the prism in point C.

In turn, the reflected beam forms, with the normal n_c in C an incidence angle ω. Furthermore, the external angle in L of the triangle LCB is the same as β, consequently we have:

$$\beta = \omega + \gamma \text{ or } \omega = \beta - \phi - r > l$$

Because $\omega > l$, in C too we have a new total reflection and the new reflected beam encounters the base a of the prism in its point D which forms, with the normal n_D in D, an angle σ. Furthermore, because ω is also external angle in C of the triangle CMB, we have $\omega = \sigma + \phi$ hence:

$$\sigma = 2\beta - \pi - r < l$$

Because $\sigma < l$, the beam in D refracts and exits from the prism forming an angle of refraction $\lambda > \sigma$ with the normal n_D equal to

$$\Lambda = \arcsen\,[n_{1,2}{}^{*}\sen\,(\sigma)]$$

Finally, u being the beam exiting from point D and 2δ the angle between the incident beam i and u, if N indicates the intersection point between the two straight lines i and u, considering the triangle AND it appears that its angles in A and in D are respectively the complementary angles of i and λ from which we obtain

$$2\delta = i + \lambda$$

Said angle indicates the deflection undergone by the incident beam i to exit from the prism.

Using the previous formulas, the deflection becomes:

$$2\delta(i) = i + \arcsen\,\{n_{1,2}{}^{*}\sen\,[\pi - 4\phi - \arcsen\,(\sen(i)/n_{1,2})]\}$$

meaning also

$$y_1 = \sen\,(2\delta - i) = n_{1,2}{}^{*}\sen\,[\pi - 4\phi - \arcsen\,(\sen(i)/n_{1,2})] = y_2$$

As regards the values of the absolute refraction index n of the transparent means, for the calcite crystals n=1.658 and in the proximity of this value are the greater part of the transparent solids except for diamond which has n=2.465. Because the limit angle l is

$$l = \text{arcsen}(1/n)$$

it decreases with the increase of n and for calcite l=0.64 rad=38°, while for diamond it is l=23.93°.

The entrance reflective apparatus is located, on the other hand, in the vertex S of the polygon where the injection laser is also installed.

A first resolution embodiment of said apparatus is that it is formed of a semi-reflecting mirror similar to that used in almost all lasers. A further type of embodiment is that formed of an isosceles prism with total double reflection, the same as the previous ones, but shaped in such a way that the faces crossed by the injected beam are perpendicular to it, as shown in Figure 20.

The beam of the laser RL is parallel to the exiting beam RU and distant from it by a few micrometers, a distance indicated by Δ, but in such a way that the exit point D is always on the natural face of the prism.

In particular, the entrance reflective apparatus located in the vertex S must be reflective to laser pulses from inside the accumulation chamber 30 (in more detail to the left of the vertex S), and must in turn be transparent (refracting) to the pulses from the laser generator 20.

For the optimal operation of the accumulator 10, the entrance reflective apparatus must be simultaneously both reflective to laser pulses from inside the accumulation chamber 30 and transparent to the laser pulses from the laser generator 20, but this would produce an interference which results in a diffusion of the two laser pulses deflecting them from the direction along the chord of the star polygon causing the accumulator 10 to malfunction.

It is therefore necessary that the two pulses do not encounter immediately on the entrance reflective apparatus.

Indicating by n_r the number of vertices of the star polygon, to n_r also corresponds the number of reflections required by the pulse to describe the entire polygon; and

$$f_\lambda = 1/T_\lambda$$

indicates the frequency of the pulses supplied by the laser generator 20, while

$$\Delta T_0 = 2R^*\cos(\alpha)/c, \text{ with } \alpha=180°/k$$

indicates the simple duration of the instrument.

Furthermore, as previously described, the values of k must be such that:

- if n_r is odd, $k=2*n_r$;
- if n_r is even and $n_r/2$ is even, $k=n_r$;
- if n_r is even and $n_r/2$ is odd, $k=n_r/2$.

The length P of the perimeter of the star polygon with side ℓ therefore becomes:

$$P = n_r^* \Delta T_0^* c = n_r^* 2R^* \cos(\alpha), \text{ with } \ell = 2R^* \cos(\alpha).$$

The distance between two subsequent pulses is given by λ and is:

$$\lambda = c^* T_\lambda = c/f_\lambda.$$

The number of pulses and the pulse fraction necessary so that the initial pulse returns to the vertex S are defined by the relation:

$$\rho_0 = L/\lambda = n_r\, T_0\, f_\lambda = n_r T_0 / T_\lambda.$$

In the case ρ_0 is integer, after exactly ρ_0 pulses, the initial pulse emitted by the laser generator 20 returns to the vertex S.

Alternatively, if ρ_0 is not integer and defining m = m.c.m.(P; λ) as minimum common multiple between P and λ, then m is divisible by λ and the relation

$$\rho = m/\lambda$$

is an integer number and indicates the minimum number of pulses required for the initial pulse to return to the vertex S.

In this case, the pulse is said to have covered a complete cycle of length m formed by C = m/P complete polygons.

The formula relating to the minimum number of pulses can be rewritten as:

$$\rho = C^* P/\lambda = n_r^* T_0^* C/T_\lambda = \rho_0^* C.$$

If P and λ are co-prime numbers, we have:

$$m = P^* \lambda,\ \rho = P \text{ and } C = \lambda.$$

Finally from the known property of the maximum common denominator (M.C.D.) and of the minimum common multiple (m.c.m.) we obtain:

$$\text{M.C.D.}(P;\lambda) = P^* \lambda/m = P/\rho = \lambda/C.$$

To be able to charge the accumulator 10 with a high number of pulses, the total energy of which permits the implosion of the target 60, in a single complete cycle a charging time is required of just one cycle itself which is

$$T_C = T_0^* n_r^* C = \rho^* T_\lambda.$$

In the case of P and λ being co-prime numbers, then $T_C = T_0^* n_r^* \lambda$.

As regards the energy quantities of the accumulator 10, W_f is used to indicate the power of the laser generator 20 which emits pulses with a frequency defined by the relation $f_\lambda = c/\lambda$ and $T_\lambda = \lambda/c$.

Consequently, the energy of each pulse E_a is

$$E_a = W_f{}^*T_\lambda = W_f{}^*\lambda/c,$$

while the energy of a cycle is

$$E_C = \rho^*E_a = \rho^*W_f{}^*\lambda/c = m^*W_f/c = \rho^*W_f{}^*T_\lambda.$$

Vice versa, to build a cycle of a laser with given radius R and given power W_f and frequency $f_\lambda(\lambda)$, such as to have an assigned cycle energy $\bar{E}_C$, this must be:

$$\rho = \bar{E}_C/E_a = \bar{E}_C/W_f{}^*T_\lambda,$$

$$\lambda = c^*T_\lambda, \text{ and}$$

$$m = \rho^*\lambda = c^*\,\bar{E}_C/W_f.$$

If ρ and λ are co-prime numbers then $C=\lambda$, $P=\rho$ and $n_r{}^*\cos(180°/k) = P/2R$ or $\ell=2R^*\cos(180°/k)$, where the value of k depends on n_r according to what has been previously seen.

In the case of n_r not being integer and positive, this means $\bar{E}_C$ is not exactly separable on complete cycles.

If ρ and λ are not co-prime numbers, a system can be defined made up of the following equations:

$$C^*P = m$$

$$n_r{}^*\cos(180°/k) = P/2R$$

called Diophantine system in the integer variables n_r, P, C.

If the system has no solutions, this means $\bar{E}_C$ is not exactly separable on complete cycles.

By way of example, if we consider P=7 m=70 dm and λ=1.2 m=12 dm then $T_\lambda = \lambda/c = 4^*10^{-9}$ s, m=420 dm=42 m, C=6 complete polygons and ρ=35 laser pulses.

If the star polygon is a pentagon n_r =5 then k=10 and α=360°/10=36° and $R=P/(2n_r{}^*\cos\alpha) = 0.865$ m; moreover the sides of the star measure l = 7/5 = 1.4 m.

In this case, because the instrument has a radius of 0.865 m it can be considered as a small-size laboratory prototype.

If the effective power of the laser generator 20 is $W_f = 10^5$ W, to obtain the implosion of a standard capsule (target 60) having a surface $S = 3.14*10^{-3}$ cm^2 an energy $E = 1.8^*10^6$ J is needed, therefore, being $E=W_f{}^*\Delta T$, $E_a=W_f{}^*T_\lambda=4^*10^{-4}$ J, we have

$$\Delta T = E/W_f = 18 \text{ s and } \Delta s = c*\Delta T = 5.4^*10^9 \text{ m.}$$

Furthermore, the number N_C of cycles charged to accumulate such a high energy amounts to:

$$N_C = 5.4^*10^9{:}42 = 128.571.428.$$

Because each cycle is covered by ρ =35 laser pulses, the total number of laser pulses needed to accumulate the energy E is

$N_E = N_C{}^*\rho = \Delta s/\lambda = (5.4/1.2)^*10^9 = 4.5^*10^9$;

the energy of each pulse is $E_a = J_f = (1.8/4.5)^*10^{-3} = 4^*10^{-4}$ J, while the frequency becomes $f_\lambda = N_E/\Delta T = c/\lambda = 2.5^*10^8\ s^{-1} = 1/T_\lambda$.

This example, being that of a small-size laser generator, the cycle of which contains 35 laser pulses, requires a high number of cycles N_c to accumulate high energies.

To build a cycle containing the implosion energy E, for an assigned laser generator 20 (given W_f and λ) where $\bar{E}_C = E = 1.8^*10^6$ J we obtain that:

$\rho = \bar{E}_C/E_a = \bar{E}_C/W_f{}^*T_\lambda = 4.5^*10^9 = N_E$,

$m = \rho^*\lambda = 5.4^*10^9$ m= Δs.

P (or C) is not determinable except with the Diophantine system equation ($n_r{}^*\cos(180°/k) = L/2R$) when it admits integer solutions n_r and P.

In case of n_r also being known, α is calculated and then P.

To be able to charge the laser generator with high energy, each pulse must return to the vertex S after covering a high number of polygons, where such number is obtainable by means of the equation C=m/P.

Furthermore ρ must be very high and λ very small. The spatial dimensions and physical quantities of the accumulator 10 are substantially reduced and, consequently, it is easy to make at a cost which is not high. Since the laser generator 20 has a low power, to make more efficient instruments (with smaller ΔT), the E_a values must be higher.

If for instance we take $E_a = 10^4$ J and the accumulator 10 used has L= 101 m and λ=2100 m we obtain:

$m=212100$, $\rho = L = 101^*T_\lambda = \lambda/c = 7^*10^{-6}$ s, $f_\lambda = 1/T_\lambda = 1.428^*10^5\ s^{-1}$,

$W_f = f_\lambda{}^*E_a = 1.428$ GW,

being $R = P/(2n_r{}^*\cos(\alpha))$, if $n_r=5$ and $\alpha=18^\circ$ we obtain R=10.62 m.

This accumulator 10 achieves the implosion energy for a standard capsule with 10 mg of molecules DT (r=0.25 mm), containing deuterium and tritium, precisely $E=1.8^*10^6$ J after a time $\Delta T=E/W_f = 1.6^* 10^{-3}$s and a frequency of implosions equal to $f_{im.}=790$ implosions/s.

By way of example, to obtain the implosion of a standard capsule with 10mg of fuel DT (containing deuterium and tritium) a laser pulse is needed with energy between 3 MJ and 5 MJ and to power a powerful electric turbine, a frequency of implosions f_{im} is required between 1 Hz and 10 Hz.

The use of an accumulator 10 having an accumulation chamber 30 with dimensions R=10.62 m and a laser generator 20 having considerable power (1.43 GW) is equivalent to the use of about one hundred turbines of the previous case.

We underline that by means of this invention it is possible first to accumulate light energy and then concentrate this high light energy at the point of convergence also using a source of low-consumption and low-cost light beams, e.g. with respect to the prior art, while maintaining high performance.

CLAIMS

1) Accumulator (10) of light energy, characterized in that it comprises:

- at least one source (20) of a light beam;
- an accumulation chamber (30) with at least an entrance (31) through which the laser beam enters the accumulation chamber (30);
- a plurality of reflective elements (40) arranged within the accumulation chamber (30) and oriented to reflect the laser beam along at least a closed reflection path; and
- deflector means adapted to deflect simultaneously the direction of at least one reflected light beam (B) from each of the reflective elements (40) towards a point of convergence (O), said deflector means comprising a plurality of deflector elements (50), each aligned with a respective reflective element (40) along the respective stretch of reflection path and switchable alternately between a non-reflection configuration at least with a laser beam incident (A) on each of the reflective elements (40), and a reflection configuration at least with the laser beam incident (A) on each of the reflective elements (40), wherein each of said deflector elements (50) in said reflection configuration is adapted to reflect the incident laser beam (A) by deflecting it from the reflection path towards said point of convergence (O) of said reflected light beams (B).

2) Accumulator (10) according to claim 1, characterized in that each source (20) comprises at least one laser generator.

3) Accumulator (10) according to claim 2, characterized in that each laser generator (20) is of the continuous type.

4) Accumulator (10) according to claim 2, characterized in that each laser generator (20) is of the pulse type.

5) Accumulator (10) according to one or more of the preceding claims, characterized in that said accumulation chamber (30) has a substantially cylindrical shape.

6) Accumulator (10) according to one or more of the preceding claims, characterized in that each of said reflective elements (40) of said plurality of reflective elements is positioned at the vertices of an imaginary regular polygon inscribed in an imaginary circumference.

7) Accumulator (10) according to one or more of the preceding claims, characterized in that said accumulation chamber (30) has a substantially spherical shape.

8) Accumulator (10) according to one or more of the preceding claims, characterized in that each of said reflective elements (40) of said plurality of reflective elements are positioned at the vertices of an imaginary simple polyhedron inscribed in an imaginary circumference.

9) Accumulator (10) according to one or more of the preceding claims, characterized in that each reflective element (40) comprises at least one saturable absorber mirror (41).

10) Accumulator (10) according to one or more of the preceding claims, characterized in that each reflective element (40) comprises at least one gain medium (42).

11) Accumulator (10) according to one or more of the preceding claims, characterized in that each deflector element (50) comprises at least one Pockels cell (51) connected to power supply means (52) of an electric field, said Pockels cell (51) being configured to be switched between the non-reflection configuration, wherein it is transparent to the incident light beam (A), and the reflection configuration, wherein it is reflective with respect to the incident light beam (A), according to the power supply electric field it is subjected to.

12) Accumulator (10) according to claim 11, characterized in that said Pockels cell (51) comprises at least an optical crystal of potassium dihydrogen phosphate.

13) Accumulator (10) according to one or more of the preceding claims, characterized in that each deflector element (50) comprises at least one mirror (53), the reflection plane of which is inclined with respect to the reflection plane of the reflective element (40) and is associated movable inside the accumulation chamber (30) alternatively between the non-reflection configuration, wherein the mirror (53) is misaligned with respect to the direction of the incident light beam (A) along the reflection path, and the reflection configuration, wherein the mirror (53) is aligned with the direction of the incident light beam (A) along the reflection path.

14) Accumulator (10) according to one or more of the preceding claims, characterized in that it comprises means (32) to form the vacuum inside the accumulation chamber (30).

15) Method for the accumulation of light energy which comprises the steps of:

- directing at least one light beam along a reflection path defined by a closed broken line, wherein onto each vertex of the reflection path converge an incident light beam (A) and a reflected light beam (B) of the light beam; and
- deflecting instantaneously the reflected light beams (B) of the light beam into a single point of convergence (O).

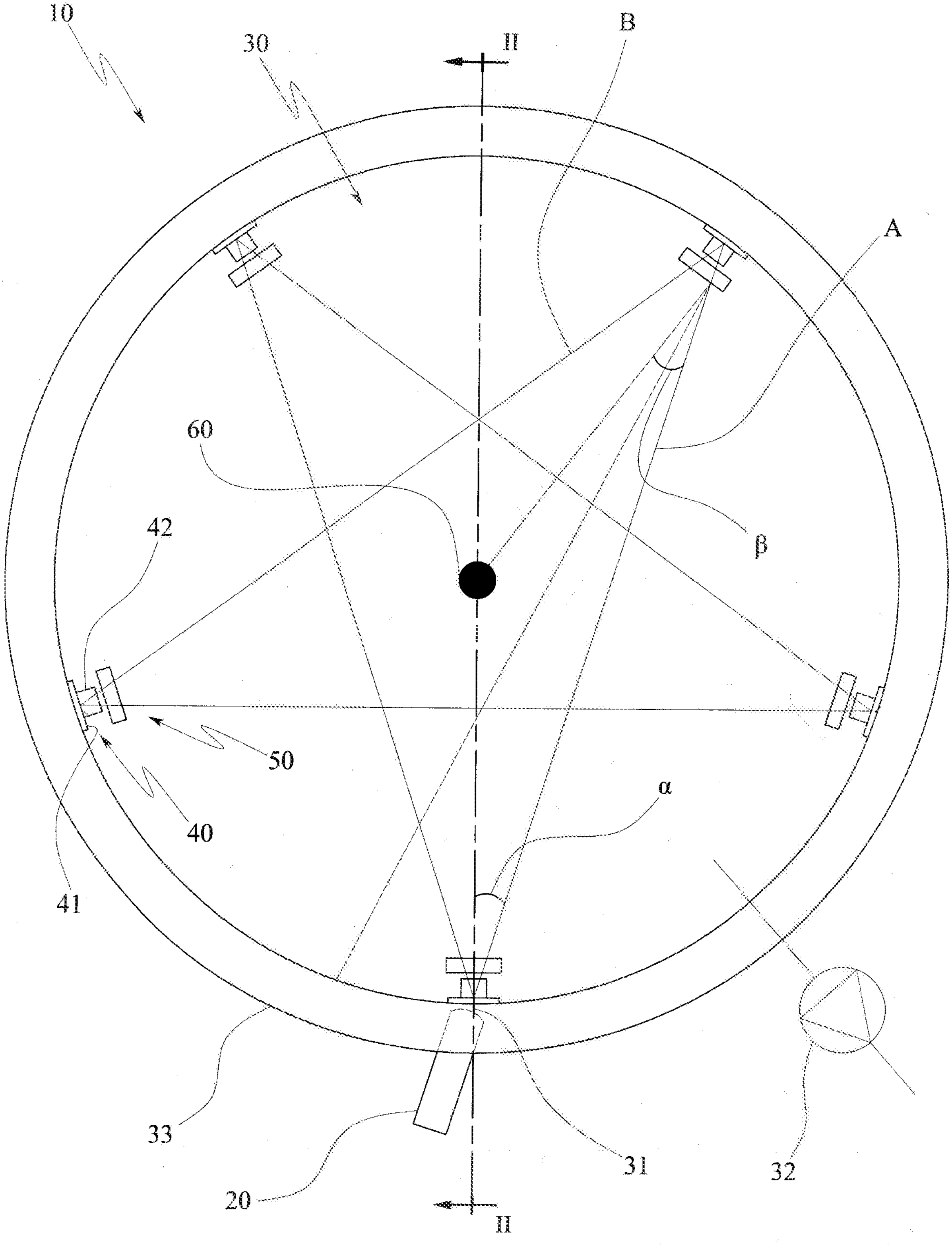


Fig.1

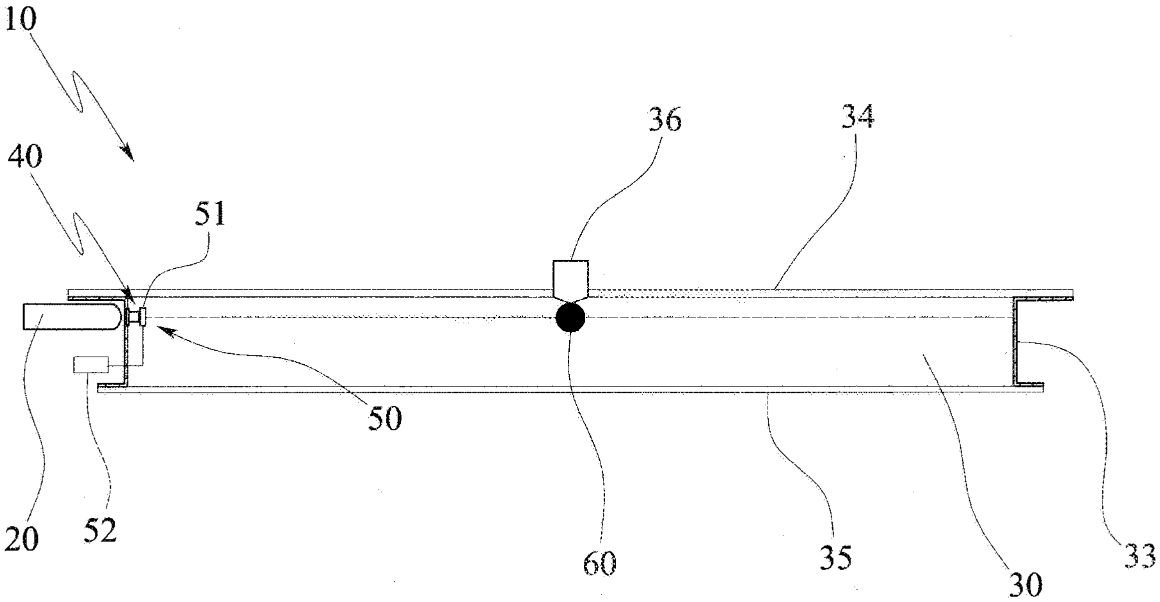


Fig.2

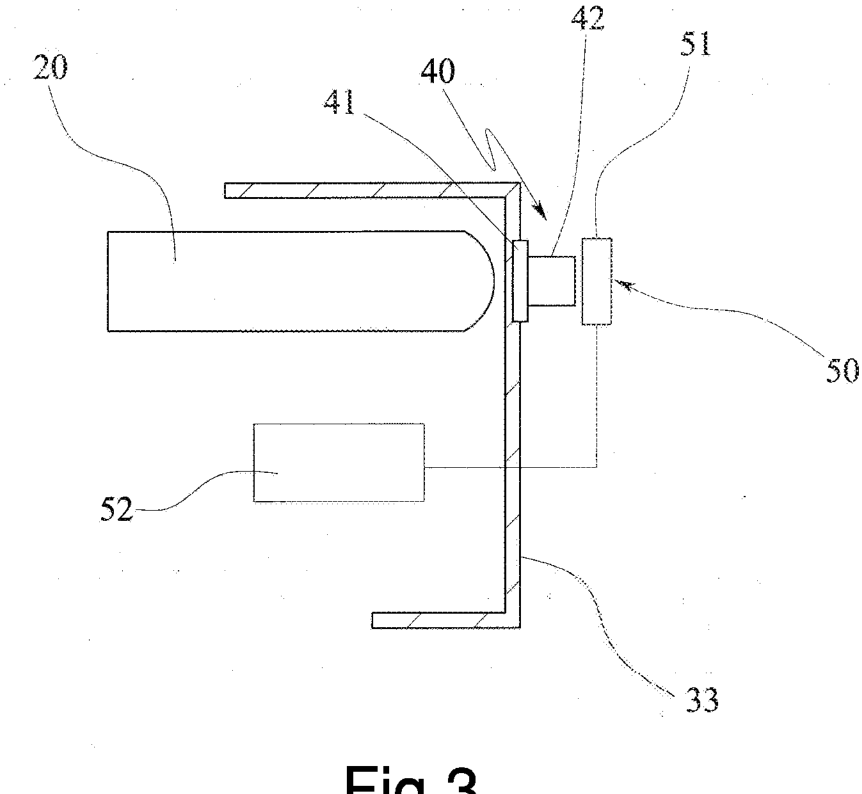


Fig.3

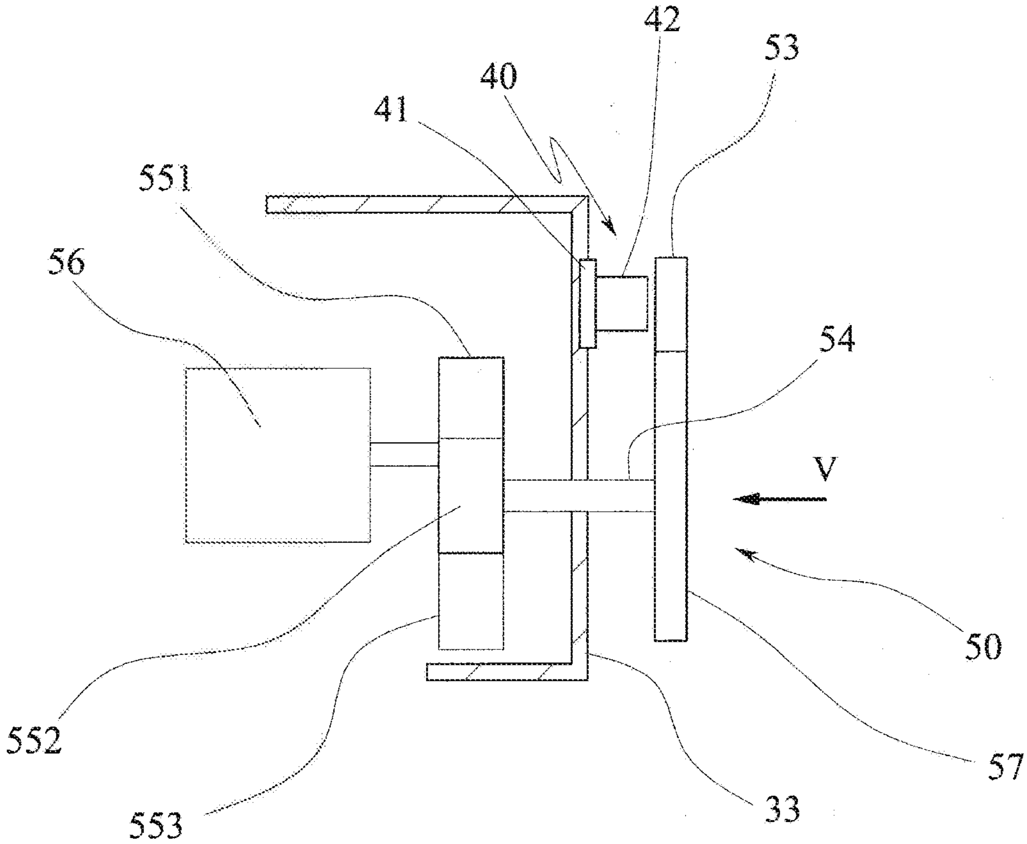


Fig.4

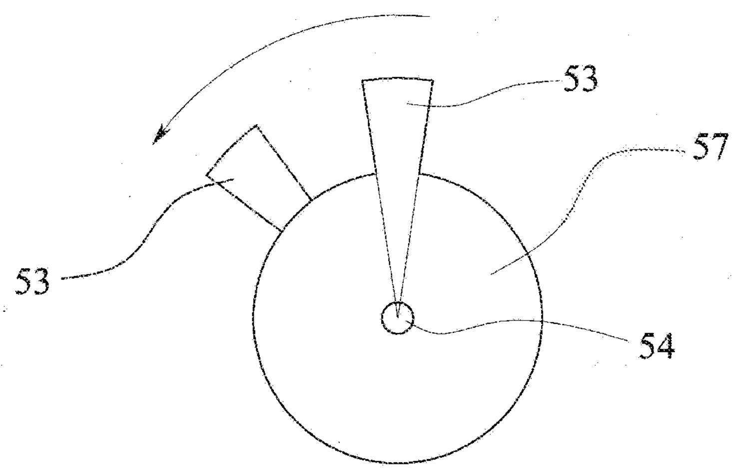
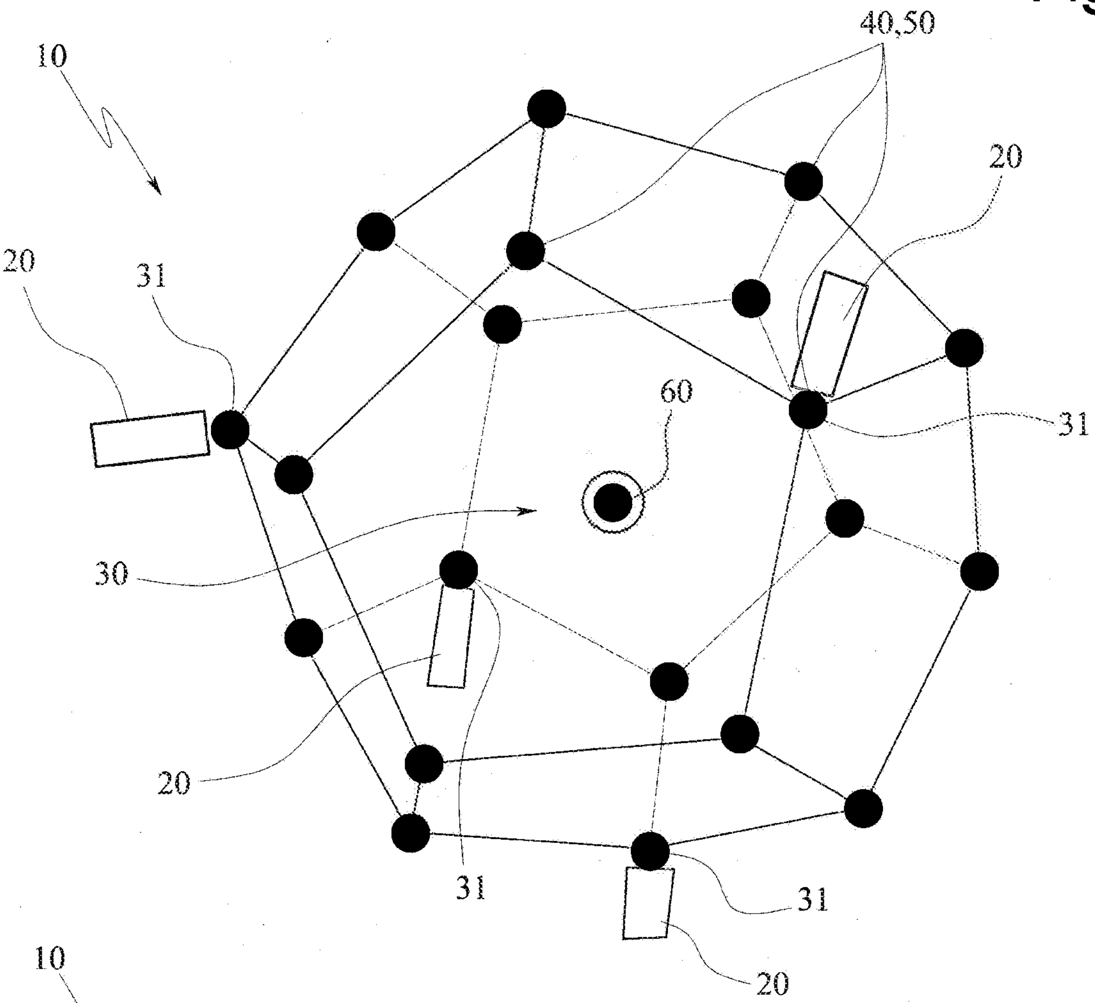


Fig.5

Fig.6



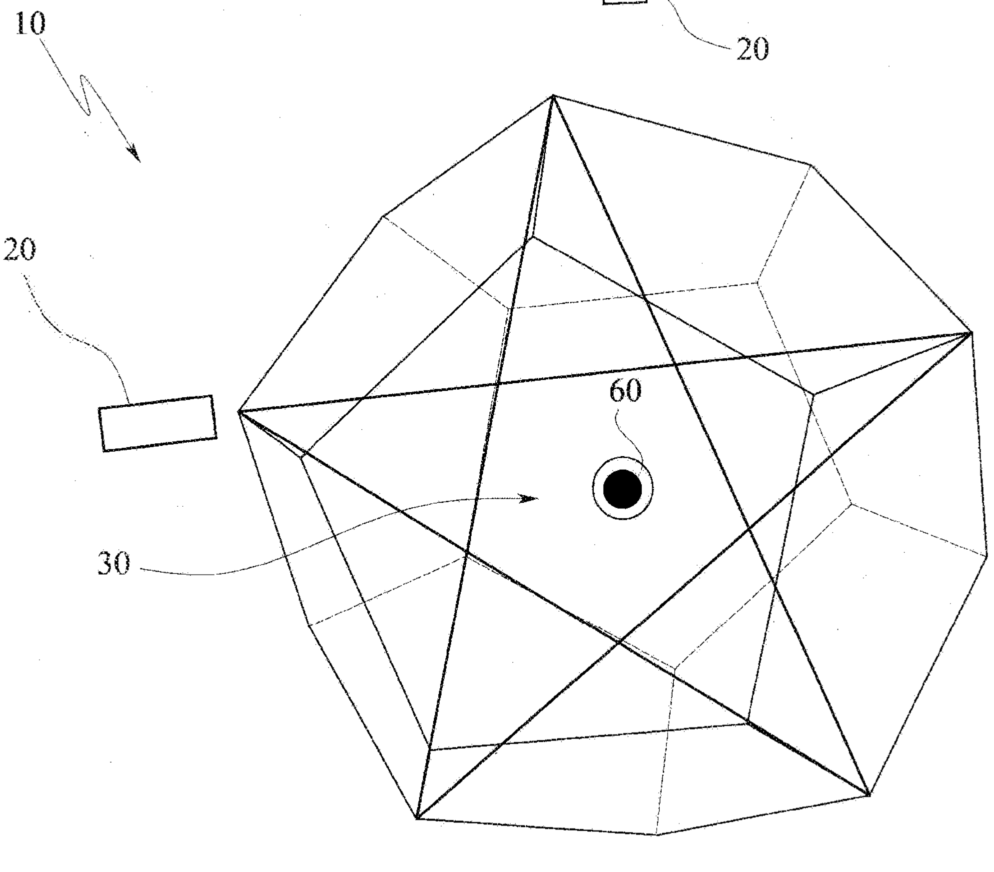


Fig.7

Fig.8

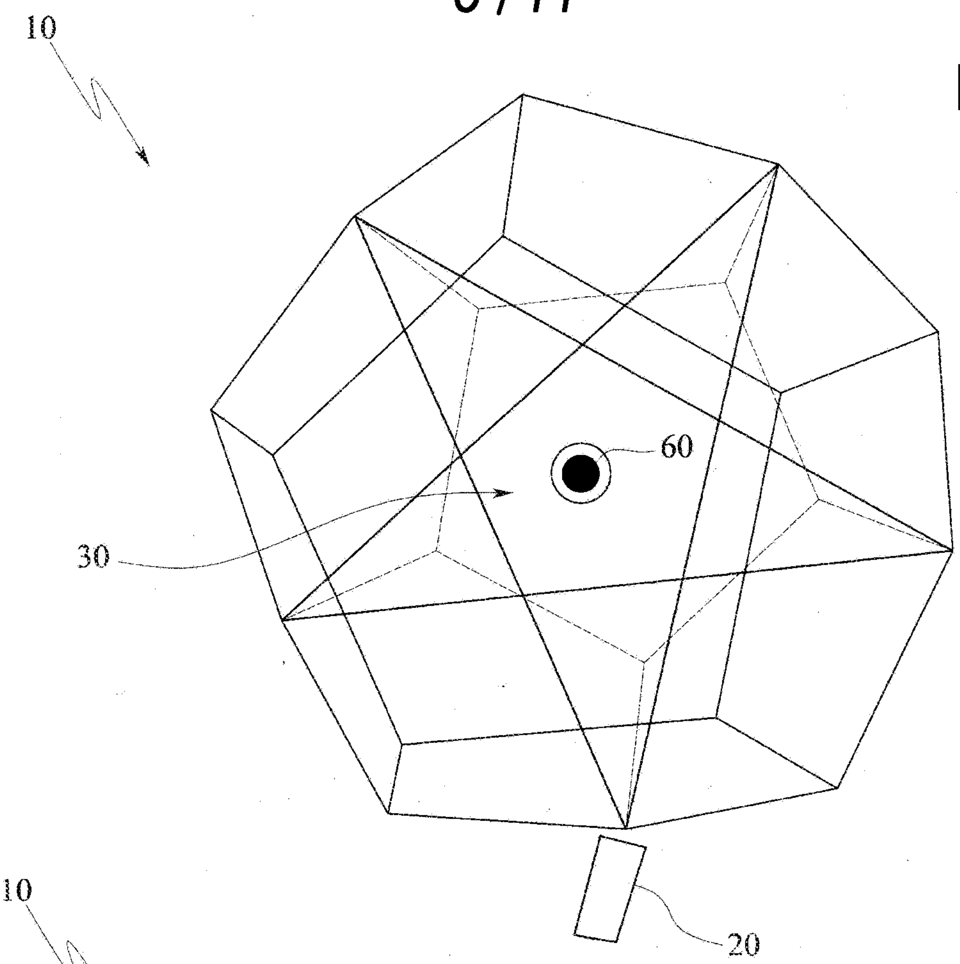


Fig.9

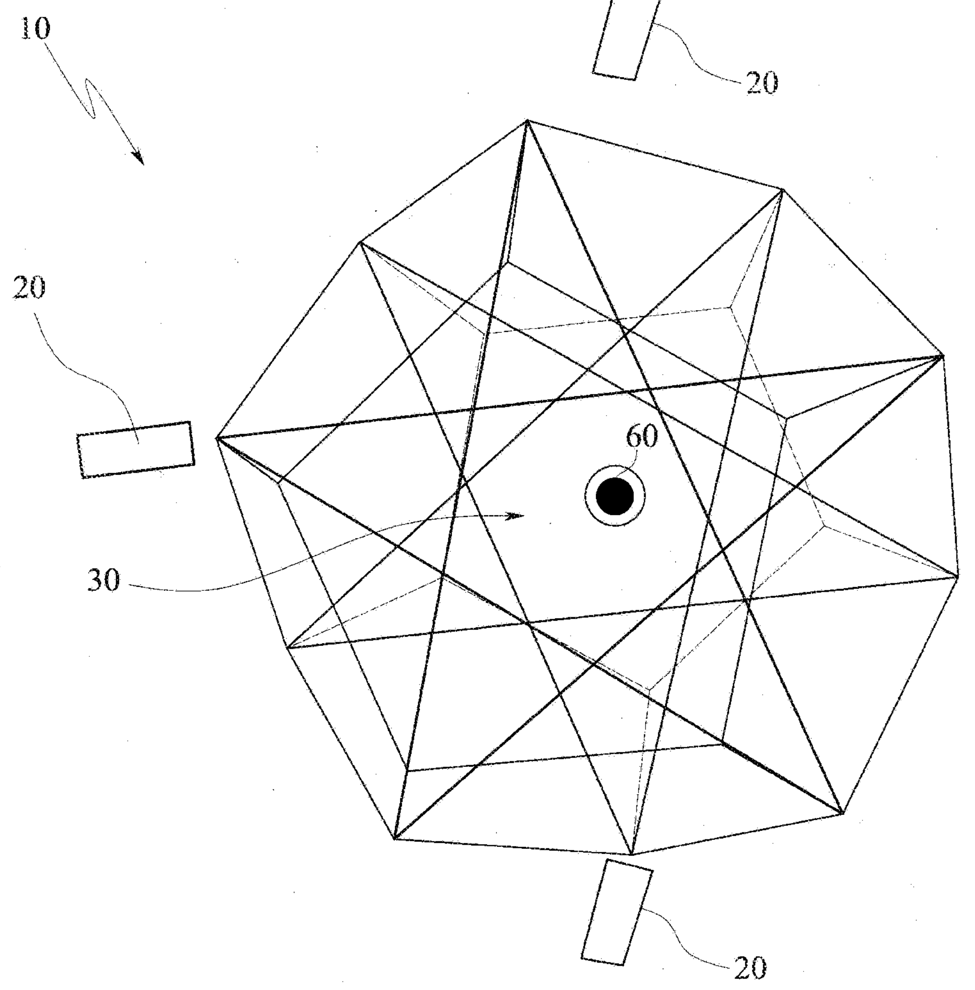
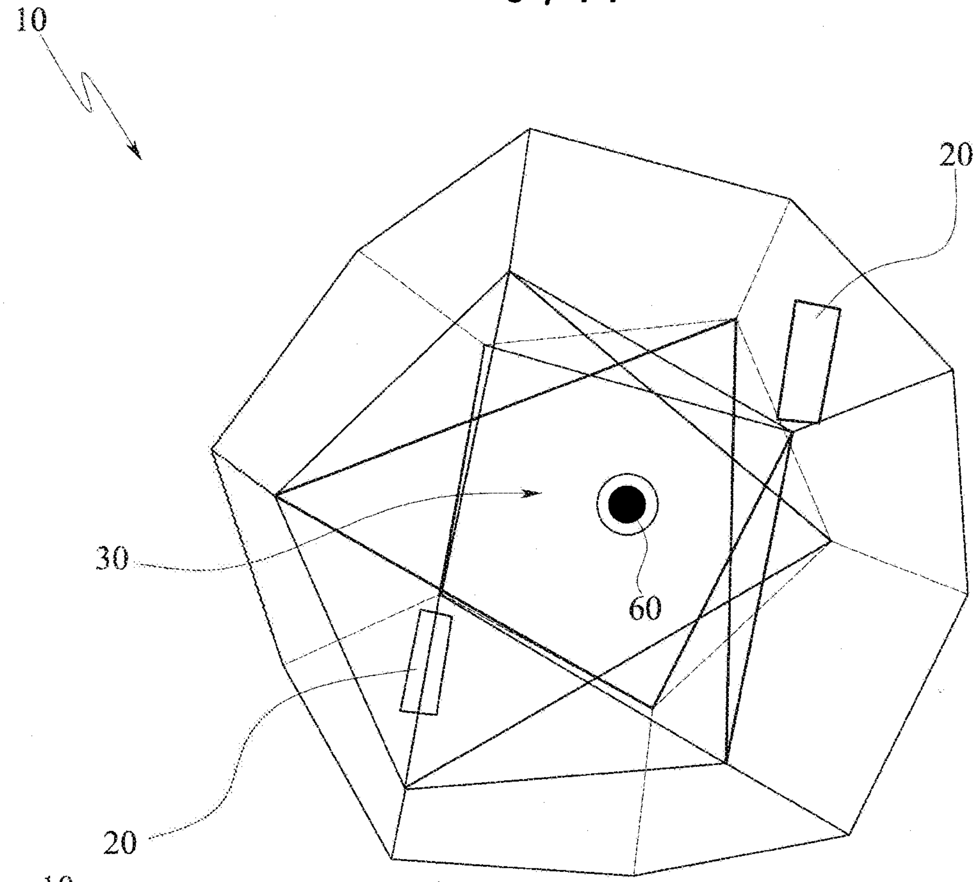


Fig.10



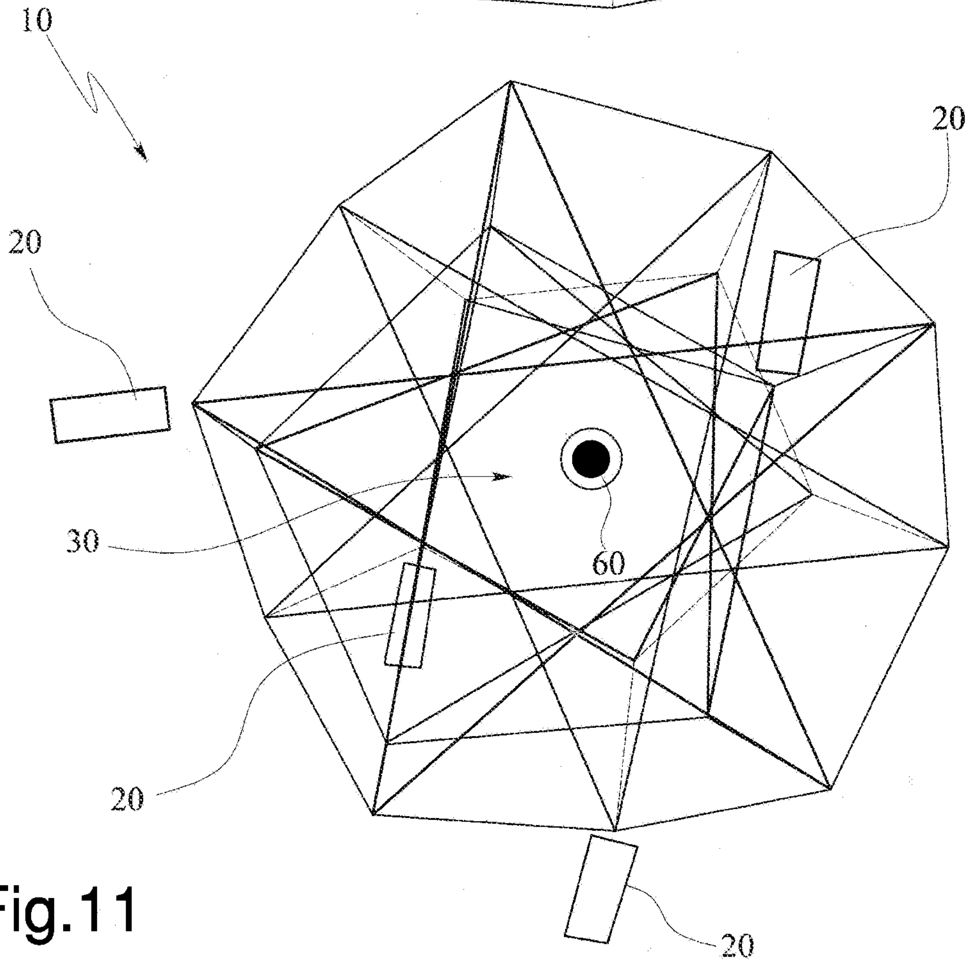


Fig.11

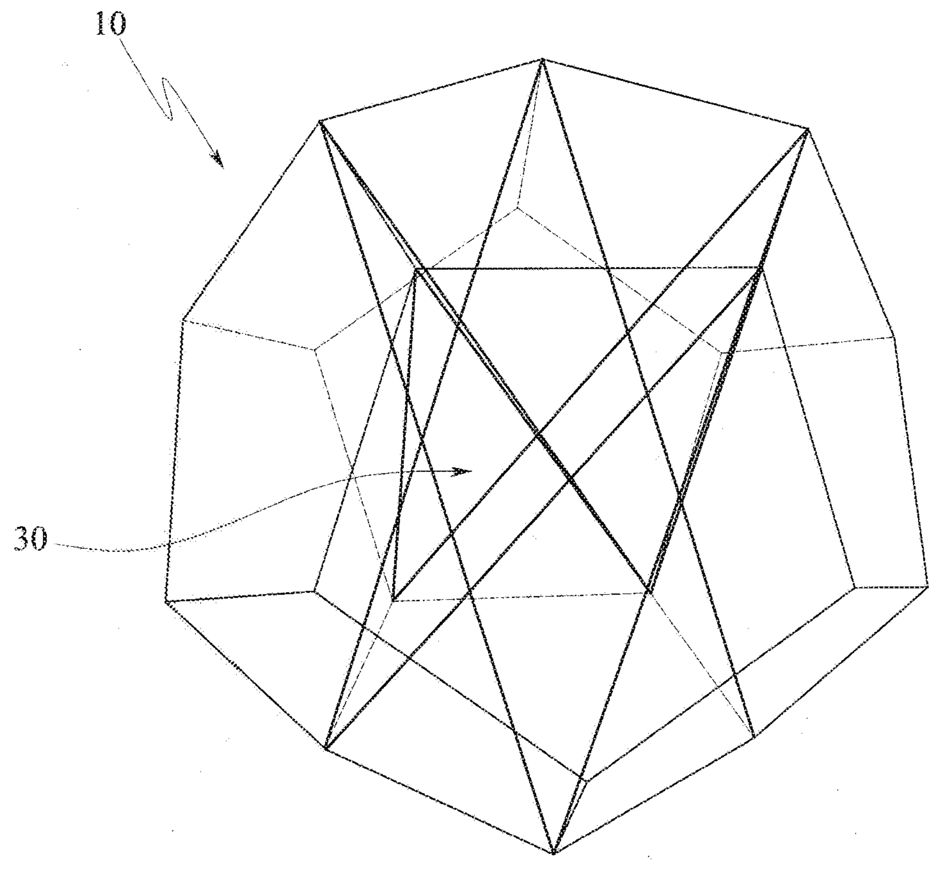


Fig.12

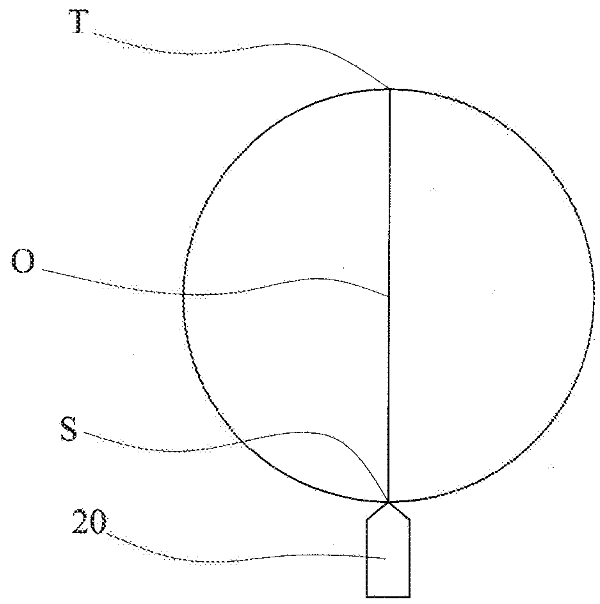


Fig.13

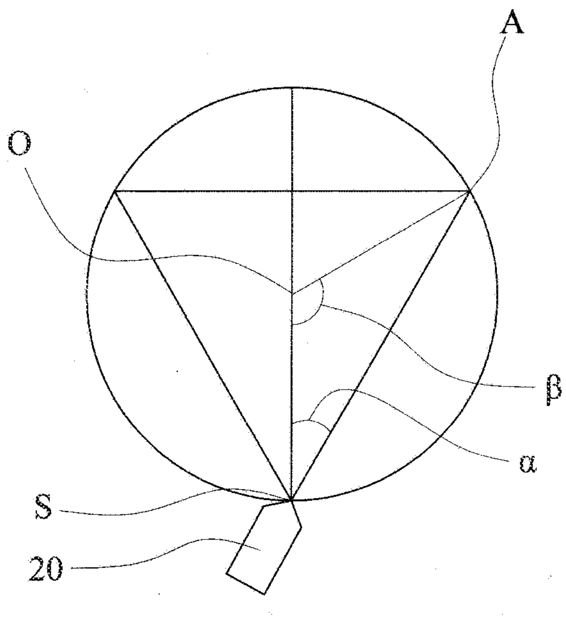


Fig.14

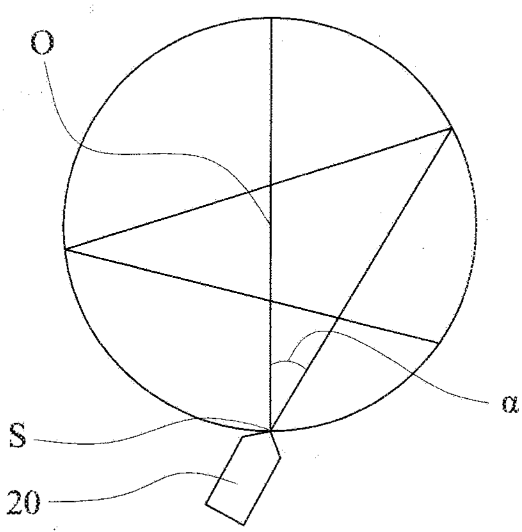


Fig.15

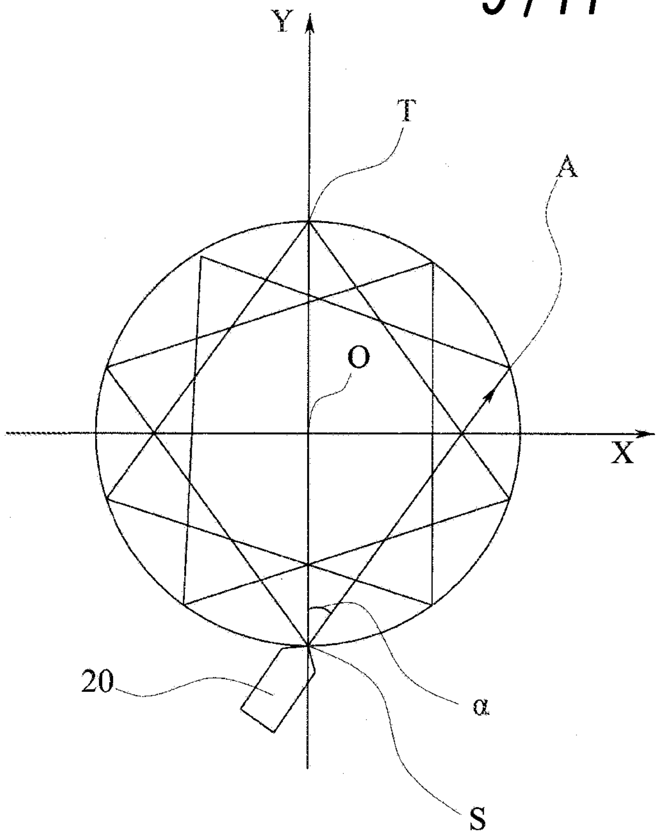


Fig.16

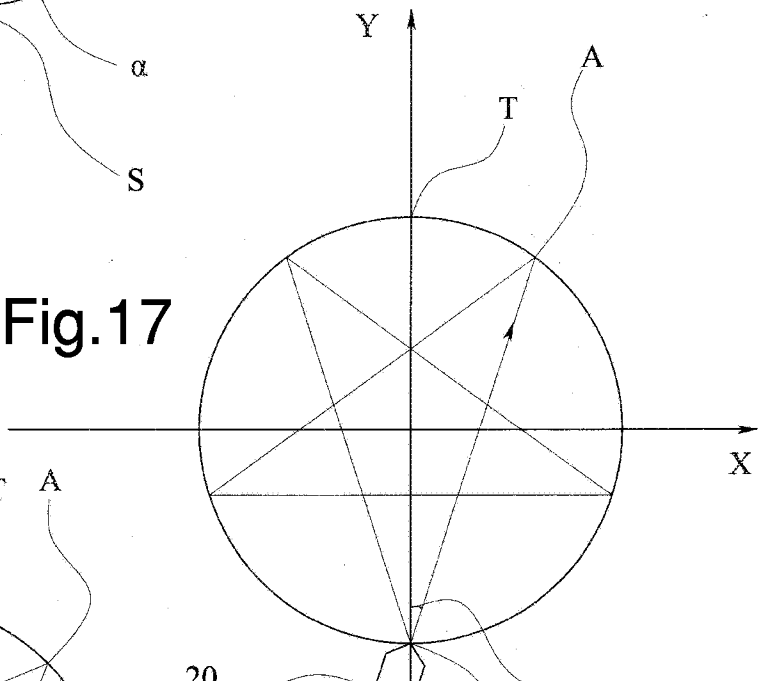


Fig.17

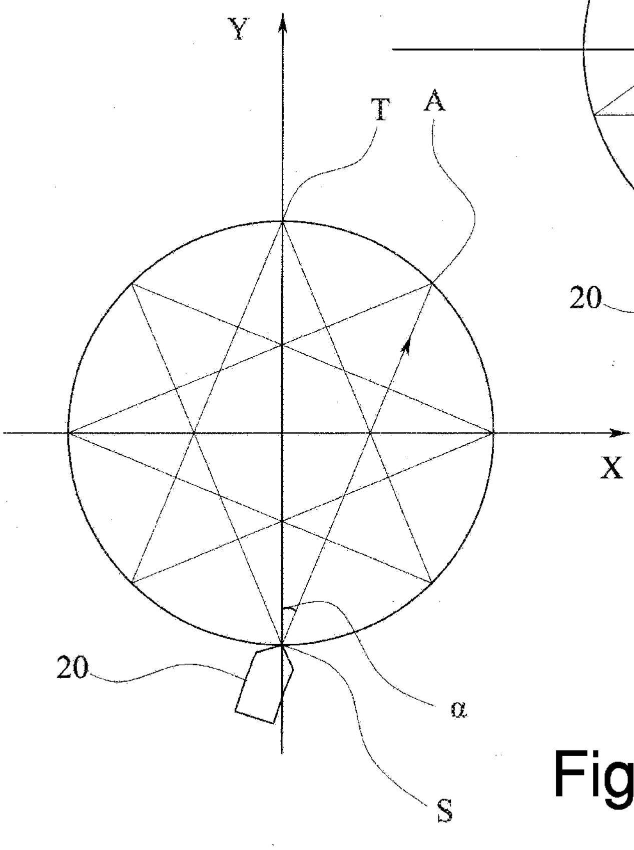


Fig.18

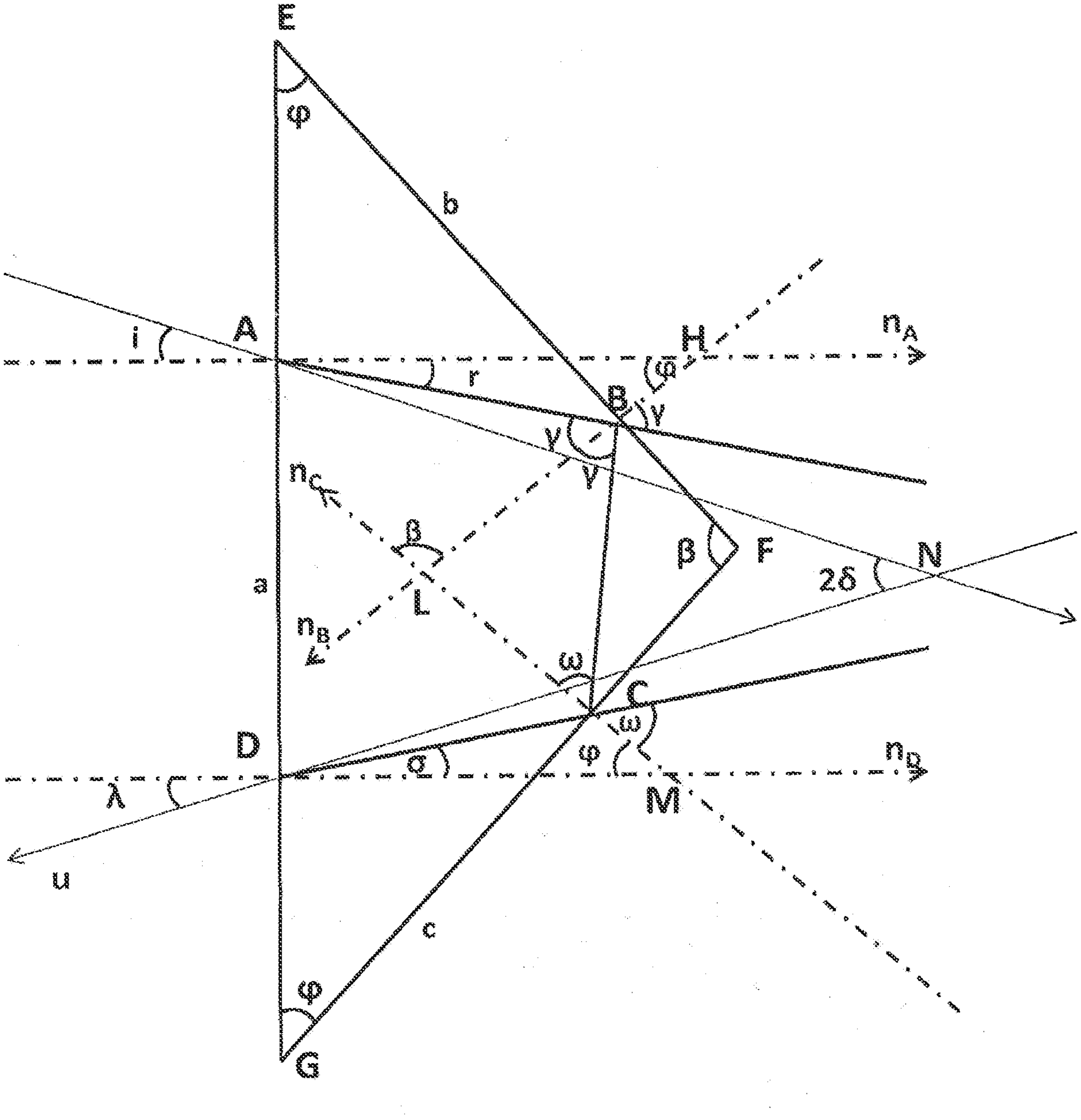


Fig.19

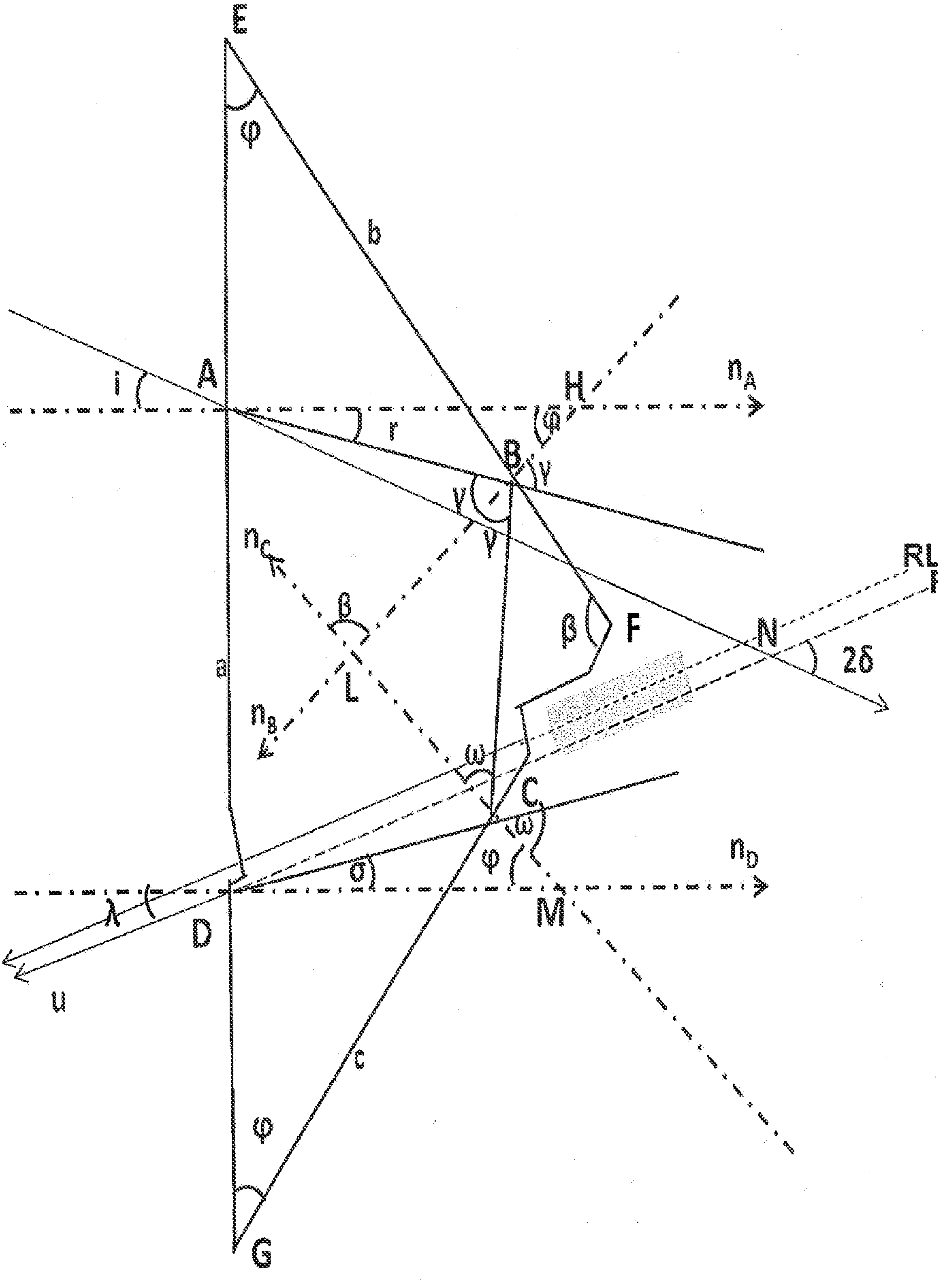


Fig.20

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2016/050678

A. CLASSIFICATION OF SUBJECT MATTER
INV. G21B1/23 H01S3/107
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G21B H01S

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X A	US 2012/114008 A1 (BAYRAMIAN ANDREW JAMES [US] ET AL) 10 May 2012 (2012-05-10) figure 9 paragraph [0072] - paragraph [0074] -----	15 1-14
A	AU 646 465 B2 (AUSTRALIAN ELECTRO OPTICS) 24 February 1994 (1994-02-24) page 5, line 3 - page 7, line 24 figure 1 -----	1,14
A	US 3 764 466 A (DAWSON J) 9 October 1973 (1973-10-09) figure 1a column 8, line 11 - column 12, line 66 -----	1
A	US 4 657 721 A (THOMAS CARLTON E [US]) 14 April 1987 (1987-04-14) figures 2-3 column 2, line 47 - column 3, line 45 -----	1

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
28 April 2016	11/05/2016

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Clemente, Gianluigi

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
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