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DESIGN AND ANALYSIS OF CONCENTRIC DIAMOND BEAM DEFENSE SYSTEM – CONTEMPORARY LASER WEAPONRY

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KeyWords

Concentric Diamond Beam, Starshot Initiative, ultra-high power, trajectory displacement, red flagged zone, atmospheric attenuation, target reflectivity, passive components, beamlets, beam source, converging beam, laser weaponry.

ABSTRACT

The application of laser technology is fast expanding as research continue to increase the power limits of combined beam output. One area of interest is the laser weaponry system which is gradually replacing bullet and rocket systems due to its superior benefits. However, due to low power limits, laser beams will have to be focused on targets (i.e missile, armoured vehicle, spy aircrafts) for prolonged time before total destruction can be achieved. Factors such as reflectivity of target's surface, atmospheric attenuation and thickness of target affect the level of destruction. To achieve total destruction of target in the face of these factors, laser beam power beyond current limits must be used. The emergence of Concentric Diamond Beam (CDB) concept unveiled the possibility of pushing the frontiers of power scaling close to infinity. This paper leveraged the special features of the CDB concept to highlight an approach to contemporary laser weaponry that will be useful as defense system against mobile and stationary targets. The paper draws on the equations of CDB concept to explain important aspects of the design such as target aiming, intensity selection, and target displacement. The primary focus of the design was to avoid the use of passive components in power scaling and to reduce effective focus time. This leads to instant distraction of target as the ultimate benefit. The design also makes it possible to destroy targets at extremely far locations.

I. Background

The world is at the brink of global war (World War III) with conflicts ever rising between countries and within countries. Defense systems are gaining prominence due to their role in restoring confidence amongst people especially in red flagged zones. Among the current options to weaponry designs for defense systems, laser defense systems (LDS) are prioritized over bullets and rockets due to the many advantages of the former over the latter[1]. For laser weapons to achieve full scale and timeous destruction of target, the power level of the beam applied must be high enough[2]. Targets may include spy aircrafts, missiles, and armored vehicles[3]. Present laser weapon designs available use laser sources with power levels of the order of 74 kW, partly due to the limitations of the power scaling methods deployed[1,4]. As a result, current designs of Laser Weapon require that, the beam should be focused on the target for prolonged time before destruction can occur. The level of destruction is affected by factors such as beam power, atmospheric attenuation, reflectivity of the target and focus time.

Most targets are mobile and so, longer focus time may not be possible as targets may escape focus before destruction occurs. Also, contemporary missile and spy aircraft manufacturers may adjust to current designs of laser defense systems by producing surfaces with extremely high reflectivity. Moreso, in regimes of massive recurrent attacks, a defense system may have to pin down several targets within short intervals. All of these scenarios require significant reduction in focus time. Reducing focus time must be compensated with increase in beam power to achieve the same level of destruction for constant atmospheric attenuation and target reflectivity.

To overcome this challenge, the design requires a model that allows for ultra-high laser power generation. Such designs should also allow for power variation to ensure efficiency of power consumption. By extension, thicker and heavier targets should be fired with higher power levels than lighter targets. The concentric diamond beam approach to power scaling promises ultra-high combined beam powers above current limits[5]. The concept also allows laser output power to be varied based on target dimensions. Among other aspects, the paper analyzes power variation/intensity selection, aiming angles and target displacement.

Traditional laser weapon designs include the beam source (source of laser power), sensors for identifying targets and tracking them, passive optical components for converging beams at target location. The focus of this design is to eliminate the role of passive optical components in the power scaling line. The presence of passive components limit the laser power output to the order of 100 kW. Although this exceeds the threshold for target destruction, laser powers of this order require longer focus time to allow targets to absorb enough heat for destruction to be triggered. On the other hand, the CDB defense system rely solely on active components in the power scaling line, leading to the generation of ultra-high beam power and instant destruction of targets as desired by users of defense systems.

II. Concentric Diamond Beam Defense System

The CDB Defense System consist of a source of ultra-high-power laser, target identification and tracking system, central control system and impact data retriever. The system avoids the power scaling limitations associated with the use of passive components.

Figure 1. A diagram of the concentric Diamond Ring Weapon shooting at targets P_0, P1, P_2, and P_3. Beams from the 1st order ring are bolden to differentiate from higher order beams. Dotted lines are note rays.

The diagram above shows the base control and the upper unit - laser beam arms from three rings. The beam focusing axis and focusing angle constitute the base dimension which together dictate the direction of the laser beam shot. In Figure 1., the beams are directed at (P_i, ʒ$_i^0$) which is north – east to the origin at a distance P_{io} from the beam source. The design allows for free rotation within all the quadrants about the origin. The focusing angle is programmed to vary based on inputs from the target detection unit. The work of the weapon base ends at focusing the beams precisely on the target. The beam arms are responsible for extension of distance OP_i by varying the beam angles α_i^0. For far targets, the control system increases the beam angles (α_i^0) of the beam arms from the rings to push the point of convergence further away. For near targets, beam angles are reduced to bring the point of convergence near. By doing this, extremely far targets can be aimed and destroyed with this system.

The upper unit is made up of several laser beams shot from beam arms that are packed densely in the form of concentric cycles[5] as depicted in Figure 1. If we adjust the beam angles slowly, equally and continuously, point P_i will correspondingly move as if it were a point object. The pushing force associated with this, will increase the damage of the target. The system consist of several rings of beam arms and each ring contains many closely packed beam arms depending on the requirements of the mission. To visualize this, consider the points on the circumference of a circle as laser beams coming from beam arms. All the beams are oriented to meet at common point Pi depending on the location of the target. The beam arms are positioned symmetrically to ensure that, Pi is equidistant to all points on the circumference. If we reduce the number of beamlets for simplicity of analysis to four, such that, the four beamlets constitute the vertices of a square, we obtain a structure similar to the diagram in Figure 1.

III. Rings and Beam Arms

The beam arms are the individual laser sources positioned on the circumferences of concentric circles for the purpose of this design. The design consists of several beam arms packed closely to ensure constructive interference at the far field. The arrangement of beam arms in a ring is shown in Figure 2. This can be simplified to Figure 3.

$sin\ \alpha^o = \frac{r}{r+R}$

$\alpha^o = sin^{-1}(\frac{r}{r+R})$ --------------------------- (i)

The angle subtended by the beam arms at the center of the circle is 2α.

But $\alpha^o = sin^{-1}(\frac{r}{r+R})$, from the above.

for *n* beam arms in the inner ring.

$n_o \times 2\alpha° = 360°$

$n_o = \frac{\pi}{sin^{-1}(\frac{r}{r+R})}$ --------------------------- (ii)

It follows that, for a given ring diameter R, there must be n closely packed beams to yield an optimal fill factor[5].

Figure 2. Arrangement of beam arms around the circumference of a circle.

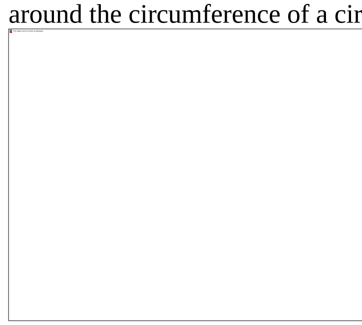

Figure 3. Simplified version of Figure 2. with one beam arm.

The CDR setup has an inner ring surrounded by outer rings to form concentric rings. The inner ring houses a single beam arm in its middle that fires directly at the target at 90º to the horizontal. The first order ring has an incremental increase in radius of $\boldsymbol{\Gamma}$. This increases the ring radius to $R_0 + \boldsymbol{\Gamma}$. From Figure c, the minimum value of $\boldsymbol{\Gamma}$ is D = 2r. From equation (1);

$n_1 = \frac{\pi}{sin^{-1}(\frac{r}{r+R_0})}$ but $R_1 = R_0 + \boldsymbol{\Gamma}$

$n_1 = \frac{\pi}{sin^{-1}(\frac{r}{r+\Gamma+R_0})}$ The minimum allowable value of $\boldsymbol{\Gamma}$ will be Γ_0 = D = 2r

$n_1 = \frac{\pi}{sin^{-1}(\frac{r}{r+2r+R_0})}$

$n_1 = \frac{\pi}{sin^{-1}(\frac{r}{3r+R_0})}$ ---------------- (iii)

It can be shown that, $n_2 = \frac{\pi}{sin^{-1}(\frac{r}{5r+Ro})}$ ------------- (iv)

$n_3 = \frac{\pi}{sin^{-1}(\frac{r}{7r+Ro})}$ -------------------- (v)

$\boldsymbol{n_i \approx n_0 + i(6)}$ **-------------------- (1)**

$\boldsymbol{n_i = \frac{\pi}{sin^{-1}(\frac{r}{(2i+1)r+Ro})}}$ **---------------- (2)**

$R_i = R_0 + i\Gamma$ -------------------- (3)

for i = 0, 1, 2, 3, ……………… N

and for all values of R at a beam radius of 0.1 cm.

From Figure 1,

$OP_i^2 = OA^2 + AP_i^2 - 2(OP_i)(AP_i)\cos\alpha_i$ ------------------------ (n)

but AP_i cannot be measured directly. From Sine Rule,

$\frac{OP_i}{\sin\alpha} = \frac{AP_i}{\sin\theta}$ if we let $AP_i = z$ and $OP_i = y$

$z = \frac{\sin\theta}{\sin\alpha} y$ where θ is angle BOP_i

Substituting this into equation (n),

$$y^2 = x^2 + \frac{\sin^2\theta}{\sin^2\alpha} y^2 - 2xy\frac{\sin\theta\cos\alpha}{\sin\alpha}$$

$$\left[1 - \frac{\sin^2\theta}{\sin^2\alpha}\right] y^2 + [2x\frac{\sin\theta\cos\alpha}{\sin\alpha}]y - x^2 = 0$$

Using the general equation $y = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$,

For $a = 1 - \frac{\sin^2\theta}{\sin^2\alpha}$, $b = 2x\frac{\sin\theta\cos\alpha}{\sin\alpha}$ and $c = -x^2$

$$y = \frac{-2x\frac{\sin\theta\cos\alpha}{\sin\alpha} \pm \sqrt{\left(2x\frac{\sin\theta\cos\alpha}{\sin\alpha}\right)^2 - 4(1 - \frac{\sin^2\theta}{\sin^2\alpha})(-x^2)}}{2(1 - \frac{\sin^2\theta}{\sin^2\alpha})}$$

$$y = \frac{-2x\frac{\sin\theta\cos\alpha}{\sin\alpha} \pm 2x\sqrt{\left(\frac{\sin^2\theta\cos^2\alpha}{\sin^2\alpha}\right) + (1 - \frac{\sin^2\theta}{\sin^2\alpha})}}{2(1 - \frac{\sin^2\theta}{\sin^2\alpha})}$$

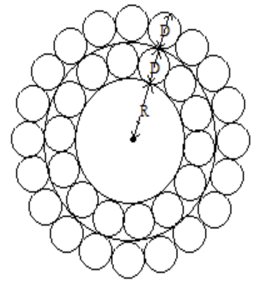

Figure 4. First order ring

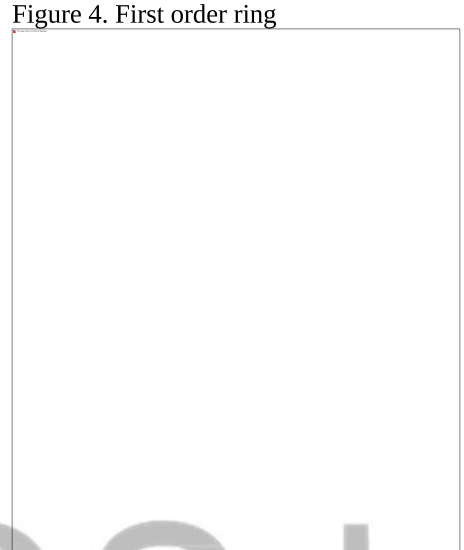

Figure 5. Beams in the N^{th} ring.

$$y = \frac{-[\frac{\sin\theta\cos\alpha}{\sin\alpha} \pm \sqrt{\left(\frac{\sin^2\theta\cos^2\alpha}{\sin^2\alpha}\right) + \left(1 - \frac{\sin^2\theta}{\sin^2\alpha}\right)}]x}{(1 - \frac{\sin^2\theta}{\sin^2\alpha})}$$

$$y = \frac{-[\frac{\sin\theta\cos\alpha}{\sin\alpha} \pm \sqrt{1 - \sin^2\theta}]x}{(1 - \frac{\sin^2\theta}{\sin^2\alpha})}$$

$$y = \frac{-[\frac{\sin\theta\cos\alpha \pm \sin\alpha\cos\theta}{\sin\alpha}]x}{\frac{\sin^2\alpha - \sin^2\theta}{\sin^2\alpha}}$$

$$y = \frac{\sin\theta\sin\alpha\cos\alpha \pm \sin^2\alpha\cos\theta}{\sin^2\theta - \sin^2\alpha} * x$$ ------------------------ (m)

For $\theta = 90^0$, $y = \frac{\sin\alpha\cos\alpha}{\cos^2\alpha} * x$

$y = \frac{\sin\alpha}{\cos\alpha} * x$

$y = x\tan\alpha$ ------------------------ (4)

Equation (4) predicts the distance from O at which the converging beams combine to destroy the target at P_i.

Again, if we consider θ = 90°, then $z^2 = y^2 + x^2$. Substituting equation (4),

$z = x\sqrt{\tan^2\alpha + 1}$ ------------------------ (5) This equation is useful in determining beam distance.

IV. Target Aiming

In this design, target aiming is in two steps;

1. Base focusing: It is the first step in getting beamlets from the respective rings to converge at the target to optimize destruction. Base focusing involves varying the focusing angle of the base, $з_i^0$ to arrive at a bearing that allows beamlets to

converge at the position of the target. This is done automatically with a central control system. Depending on the direction of the target, $\mathfrak{z}_i^0$ may be in any of the four quadrants of the Cartesian plane.

2. Beam arms focusing: It is the final step in target aiming. It involves changing the magnitude of beam angles (α_I) to arrive at a beam distance that coincides with the distance of the target from the origin O. By increasing α_I, both y and z increase until y equals the distance of target from O. This arrangement make it possible to destroy targets at extremely far locations.

From Figure 1. and applying equation (4),

$\alpha = \tan^{-1}(\frac{y}{x})$ -----------------------(x)

If we bring on the higher order rings, Figure 5. can be extracted from Figure 1.

Applying equation (9), $y = x_1 \tan\beta$

$y = (x_o + \Gamma) \tan\beta$ since $x_1 = x_o + \Gamma$ and for maximum n, $\Gamma = D = 2r$

$y = (x_o + 2r) \tan\beta$

$\beta = \tan^{-1}(\frac{y}{(2r + Xo)})$ ----------(y)

we can show similarly that,

$\gamma^o = \tan^{-1}(\frac{y}{Xo + 4r})$ -------------------- (z)

$\eta^o = \tan^{-1}(\frac{y}{(Xo + 6r)})$ ----------- (u)

To generalize the above equations, we replace α, β, γ and η with α_o, α_1, α_2 and α_3 respectively.

$\alpha_i = \tan^{-1}(\frac{y}{(Xo + 2ir)})$ ------------- (6)

For i = 0, 1, 2, 3, ... N

Where α_i is the beam angle for inner ring beams, first order beams, second order beams, third order beams and so on.

Figure 5. Beam angles of the inner ring, first, second and third order rings.

Figure 6. Base focusing in the four quadrants of the cartesian plane.

V. Intensity Selection

For the purpose of this design, intensity refers to beam energy per unit area. Intensity can be controlled by reducing the number of rings or beam arms (n). For bigger and thicker targets, higher intensity is required which implies more beam arms staying on. The more the number of beam arms switched on, the higher the combined power and the intensity rises. The central control system switches off some beam arms to reduce the combined power/intensity and switches on more beam arms to increase intensity. The level of intensity selected depends on the type of damage desired. To disable parts of the target such as, the wings of a spy aircraft, lower beam intensity is required. If the interest is to set ablaze a flammable component, smaller intensity is required. However, if a hard metallic target is to be vaporized, then ultra-high intensity beam is required. For a given size and thickness of target, beam intensity required may differ depending on degree of damage desired – i.e warning strike, lethal strike, minimal distraction, and maximum damage.

VI. Target displacement

By increasing the beam angles gradually, the central control system can adjust converging point to meet the position of the target. This is known as beam focusing. With mobile targets, target displacement may change with time and beam focusing becomes a continues task until total distraction is achieved. If all the beam arms in each ring are programmed to be lifted gradually by increasing the beam angles, then point P will be viewed as point object moving gradually away from point O.

From our previous discussions, it can be shown that;

$y_i = x \tan\alpha_i$ --------------- (7)

For a constant value of x

Equation (7) predicts the position of the beam, P_i, hence, the distance of the targe from the O.

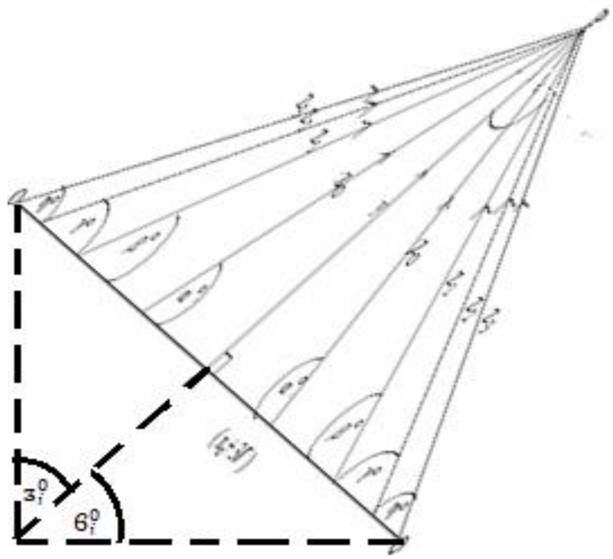

Figure 7. Increasing target displacement due to increasing beam angle.

VII. Conclusion

In conclusion, instant destruction of target is achievable with LDS, but must be done with ultra-high-power laser. The CDB Defense System is the first design of Laser Defence System with the potential of shooting out ultra-high-power beam. The design has the intelligence to detect targets at significant distance away. Using the weapon base, beamlets from different rings are positioned to converge at the target, causing the desired destruction. Some beam arms may be switched off or on to reduce or increase laser intensity depending on the damage-requirement and the type of target material. Overall, the design allows for destruction of targets at locations extremely far from reach.

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