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Design and Analysis the Fiber Laser Weapon System FLWS

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Abstract

The laser weapon system has many advantages over traditional projectile weapons such as bullets and rockets. This paper presents a new design of fiber laser weapon system FLWS. Design of FLWS requires the expansion of application fields as diverse as quantum mechanics and aerodynamics. FLWS has been designed for destruction any target, for example a spy aircrafts and missiles.

FLWS consist of 16-fiber individual of an ytterbium fiber laser with optical core radius of ~ 20µm, each fiber emitting a single-mode of CW power about 10 kW with initial beam spot size (50mm) and have a beam director radius of ~20cm

It has been demonstrated by simulations, the power needed to destroy any target made of steel (missile or aircraft) approximately about 73500watts.This represents a threshold power of FLWS, which must be overcome to destroy the target. The threshold power varies considerably depending on many factors as the range of FLWS (R_{FLWS}), attenuation of atmosphere µ and reflectivity of skin target. The quality beam of threshold power is inversely proportional to M^2 factor N-fiber and R_{FLWS}.

Keywords: Laser Weapon, Fiber laser, M^2 factor, Attenuation of atmosphere µ, Beam divergence.

1. Introduction

Laser weapons have projected always surrounded by a great deal of secrecy. The laser weapons are currently in the early stages, much of the research to be done before that up to the required level. Physical weapon can be destroying any target by delivering amounts of power, part of its absorbed by the target, causing a high rise in temperature lead to destruction. [1]

The laser weapon system includes a laser source, optics to focus the beam at the desired distance, tools for target detection and target tracking, and measures to track the target with the laser beam (fast steering mirror). Finally, a real-time computer system is needed to control the different components. [2, 3,4]

There are a number of benefits of laser weapons system:

- Laser beams propagate at the speed of light. Therefore, there is no delay from when the weapon is fired at the receiving end, as there is no need to calculate the trajectories of projectiles. In addition, the high speed of light also allows for increased accuracy with minimal aiming errors requiring no consideration of wind or leading aim of a moving target at a distance.
- Traceability of maneuverable targets by moving a mirror, where mirrors are less massive than gun and can be transferred faster.
- There is no collateral damage to the environment from the use of lasers such as bombings or hazardous chemicals.
- There are no limits in the laser’s time of operation because its do not use ammunition in the sense of a magazine of projectiles and the power source depends on the type of the laser.
- Adjust the power of laser weapon allows for the variation between a low level warning strength to a high power permanent damage level of light.

On the other hand, the disadvantages of laser weapons include it still requires huge amounts of power, reflectivity of target surface and attenuation atmosphere for the propagation of laser beam such as, scattering, absorption and turbulence. The laser weapons can be categorized according to types of energy used and the intended effects on the target. Laser weapons generate very high power, in a short period of time, spread in the air in a continuous wave or pulses. A one mega joule laser pulse delivers roughly the same energy as 200 grams of high explosive, and has the same basic effect on a target [5, 6, 7].In this paper, a laser weapon has been designed for destruction any target, for example a spy aircrafts and missiles.

2. General Design Issues

Design of FLWs requires the expansion of application fields as diverse as quantum mechanics and aerodynamics. The FLW consists of three major components of chemical lasers, optical lenses and control system.

In order for a laser weapon to destroy a target, the target skin must be heated, melted, or vaporized. For a laser to disable a target, it must concentrate its energy on certain parts of the target and hold the beam steady for a long enough time to heat the material. The effectiveness of the laser depends on the beam power, pulse duration, wavelength, air pressure, target material, target velocity, and the thickness of the target's skin [8, 9].

The exact amount of laser heated energy required (Q) to destroy a target and electronic equipment is calculated by following steps [10,11,12]:

Step 1: Calculate the amount of mass m in 1 square centimeter of the target that will be destroyed by equation:

$$m = \rho\, V = \rho(w\; l\; h) \quad \dots\dots\dots (1)$$

Where ρ density of skin material, V volume, w width, l length and h thickness of skin target (3mm).

Step 2: Calculate the energy Q_1 In joules that required to heat m grams of skin target to melting point by equation:

$$Q_1 = mC\,\Delta T \quad \dots\dots\dots (2)$$

Where (C) is the specific heat capacity of the target, (m) mass and (ΔT) is the resulting increase in temperature of the target [13].

Step 3: Calculate the energy Q_2 in joules that required melting m grams of skin target to liquid by equation:

$$Q_2 = m\,L_m \quad \dots\dots\dots (3)$$

Where $\mathbf{L_m}$ Is latent heat of melting of skin target.

Step 4: Calculate the energy Q_3 in joules that required to vaporize m grams of skin target raising the molten substance to its vaporization temperature by equation:

$$Q_3 = m\,C\,\Delta T \quad \dots\dots\dots (4)$$

Step 5: Calculate the energy $\mathrm{Q_5}$ in joules that required to vaporize them grams target’s skin by equation:

$$Q_4 = m\,L_v \quad \dots\dots\dots (5)$$

Where $\mathbf{L_v}$ is latent heat of vaporizing of skin target [14].

Step 6: Calculate the total energy $\mathrm{Q_t}$ in joules that required destroying the target by equation:

$$Q_t = Q_1 + Q_2 + Q_3 + Q_4 \quad \dots\dots\dots (6)$$

Step 7: Calculate the Power P in watt that required destroying the target by equation:

$$\mathrm{P}_t = \frac{Q_t}{t} \quad \ldots\ldots\ldots \quad (7)$$

Suppose that time t equal to 5 seconds depending on the target speed and the range of FLWs. The power from FLWs must be focused on the target long enough for the skin material to absorb the radiation. Table (1) presents a list of different targets with their velocity, burn time, skin material (often steel or aluminum), skin thickness and the Power that required destroying its target.

The power required for destroying any target depends on the reflectivity of skin and thermal conductivity. When a laser beam hits the skin of the target, a part of the energy is reflected and part absorbed in the skin. The reflectivity of skin depends on the type of material and its surface finish. A polished surface will reflect more energy than a roughened one. The reflectivity of polished of steel and aluminum around 90%.

Additionally, atmospheric losses break down into transmission, turbulence and blooming losses. Turbulence occurs because the atmosphere is not a homogeneous medium. Variations in temperature, pressure, and humidity lead to random variations in the atmosphere's index of refraction as seen by the propagating laser beam. While Blooming occurs when laser energy is absorbed by aerosols (water droplets). Thus, a good assumption for and blooming losses with the appropriate adaptive optics system is probably around 5% [5,16,17].Therefor the power needed becomes:

$$P_{needed} = \frac{\mathrm{P}_t}{1-0.95} = 20\ \mathrm{P}_t \quad \ldots\ldots\ldots \quad (8)$$

That is 20 times the P_t amounts that have been calculated above (for steel about 73500 watts). Fiber lasers can satisfy extreme power requirements. To achieve the total laser power needed for destroy the target; it is necessary to combine a large number of fiber lasers. Lasers can be combined coherently, spectrally, or incoherently.

Table (1): Data of threshold power required to destroy different targets.

Property / Target	Missile	Aircrafts
Velocity (m/s)	800-5250	50-350
Skin Material	Steel	Aluminum
Skin Thickness (mm)	1-3	1-3
C (J/gm.C^0)	0.452	0.91
Melting point (C^0)	1425	660
Vaporizing point (C^0)	2971	2467
Latent Heat of Melting $\mathbf{L_m}$ (J/gm)	250	321
Latent Heat of Vaporizing $\mathbf{L_v}$ (J/gm)	6200	10500
Density ρ (gm/cm^3)	7.87	2.70
Mass m (gm)	2.361	0.81
Energy Q_1 (J/cm^2)	1492	467
Energy Q_2(J/cm^2)	590	260
Energy Q_3(J/cm^2)	1650	1332
Energy Q_4(J/cm^2)	14639	8505
Total Energy Q_t (J/cm^2)	18371	10564
Total Power P_t (Watt)	3675	2113

In this paper, the fiber Laser Weapon System (FLWS) contains N-fiber individual of an ytterbium fiber laser with optical core radius of ~ 20µm, each fiber emitting a single-mode of CW power about 10 kW with initial beam spot size (50mm) [18,19,20], incoherently combined into one beam and fired through a beam director (see Fig.1). The 10KW, operating at central wavelength λ = 1.075 µm.

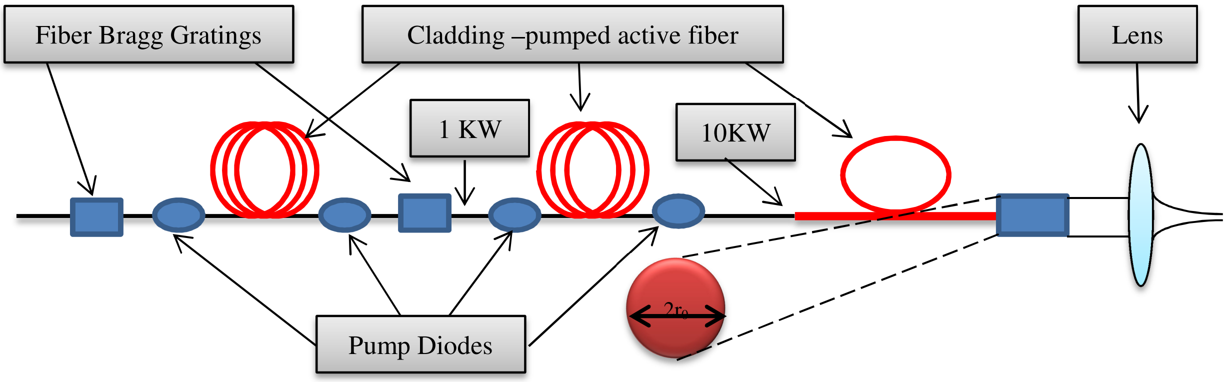

Fig (1) Schematic of Ytterbium Fiber Laser – Single Mode – 10 KW

Obviously, we need eight fibers to achieve the required power P to destroy the target. But the Atmospheric attenuation coefficient µ of the laser beam is an important factor must be calculated. µ of laser beam beyond to the absorption coefficient and scattering coefficient, but the contribution of absorption coefficient to the total attenuation is very small special for infrared laser beam, therefore the effects of scattering dominate the total attenuation coefficient. µ can be calculated by [6,7]:

$$\mu = \frac{3.912}{R_{FLWS}} \left(\frac{0.55}{\lambda}\right)^{q} \quad \ldots\ldots\ldots \quad (9)$$

Where q is the size distribution of the scattering particles, λ is wavelength in micrometer (µm) and $R_{FLWS}$is the range in Km. Table (2) shows the value of q depending on the range of FLWS.

Table (2): shows the value of q depending on the range of FLWS.

R_{FLWS}	$\leq 6\ km$	$6km < R_{FLWS} < 50\ km$	$> 50\ km$
q	$0.585\ (R_{FLWS})^{1l3}$	1.3	1.6

To calculate the number of fibers (N-fiber), must calculate the amount of the reaching power P_{reach} to the target through the earth's atmosphere which can be calculated by [20]:

$$P_{reach} = (\mathrm{N-fiber}) P_{trans} \left(\frac{\mathrm{A}_t}{(\theta_d \times \mathrm{R_{FLWS}})^2}\right) \exp\left(-\mu \mathrm{R_{FLWS}}\right) \quad \ldots\ldots\ldots \quad (10)$$

Where P_{trans}: The amount of power transmitted from FLWS, A_t: Area of spot size at target, θ_d: beam divergence in radians, $\mathrm{R_{FLWS}}$: Range of FLWS in Km and µ: Atmospheric attenuation coefficient in Km^{-1}.

The output beam of (FLWS) can be accurately modeled as a Gaussian beam. The increase in beam width with distance called Beam divergence θ_d which is limited by diffraction and optical aberrations. At near field θ_d calculated by the following equation[5,6]:

$$\theta_d = \frac{\lambda}{\pi r_0} = \frac{1.075 \times 10^{-6}}{3.14\ \times 50 \times 10^{-3}} = 6.8\,4\ \mu rad \quad \ldots\ldots\ldots \quad (11)$$

That's mean; the beam of FLWS will expand about $6.8\,4\ \mu rad$ per meter therefor the spot size of the beam at the target (r_t) of FLWS at range 14.606 km about 10 cm; i.e.

$$\theta_d = 6.8\,4 \times 10^{-6}\ \mathrm{R_{FLWS}}$$

The output beam from (FLWS) is not truly Gaussian. A quality factor, M^2 has been defined to measure the difference between an actual beam and a theoretical Gaussian. At initial spot size of beam and$\mathrm{R_{FLWS}} = 1\ m$, the M^2 value of a laser may be calculated using the following[21,22]:

$$M^2 = \frac{\pi\, r_0\ \theta_d\ \mathrm{R_{FLWS}}}{4\lambda} = \frac{3.14 \times 50\times10^{-3}\times 6.8\,4\times10^{-6}}{4\times1.075\times10^{-6}} = 0.25 \quad \dots\dots\dots \quad (12)$$

To limit diffractive spreading over the propagation range, the spot size of the beams must be large enough at the source and the beams must have good optical quality. In the absence of turbulence and mechanical jitter of atmosphere, the effective range of an incoherently combined array of single-mode lasers is determined by the Rayleigh range (Z_R) of an individual beam which is given by[23]:

$$Z_R = \frac{\pi R_0^2}{\lambda} = \frac{3.14\ (50 \times 10^{-3})^2}{1.075 \times 10^{-6}} = 7303\ m \quad \dots\dots\dots \quad (13)$$

Where R_o is the initial beam spot size and λ is the laser wavelength.

The Range of FLWS (R_{FLWS}), should be less than ~$2Z_R$, so the target range should be less than ~14606 m. For N incoherently combined fiber lasers of FLWS are achieved by overlapping the individual laser beams on a target with a beam director consisting of independently controlled steering mirrors and beam expanders as shown in Fig. 3. The total transmitted power is N times the power in the individual fiber and the beam director radius is [23]:

$$r_{BD} \approx \sqrt{N} r_0 \quad \dots\dots\dots \quad (14)$$

3.Result and Discussion

Following the design of FLWS described in the previous section the power needed to destroy any target made of steel (missile or aircraft) approximately about 73500watts (as shown in Table(1). This represents a threshold power of FLWS, which must be overcome to destroy the target. Table (3) shows the results of FLWS simulations in which the values of reaching power are directly proportional to N-fiber of FLWS and inversely proportional to the range $\mathrm{R_{FLWS}}$ as shown in Fig (2).

Table (3): shows the results of FLWS simulations in which the values of reaching power

μ (km^{-1})	R_{FLWS} (km)	N - fiber	1	8	10	12	14	16	24	31	37	57	79
2.641	1	P_{reach} (Watt)	4780	38268	47800	57360	66920	76480	114720	148180	176860	272460	377620
		M^2(Per Km)	0.25	0.707	0.790	0.866	0.935	1	1.224	1.391	1.520	1.887	2.222
1.194	2	P_{reach} (Watt)	3080	24643	30800	36960	43120	49280	73920	95480	113960	175560	243320
		M^2(Per Km)	0.5	1.414	1.581	1.732	1.870	2	2.449	2.783	3.041	3.774	4.444
0.741	3	P_{reach} (Watt)	2420	19360	24200	29040	33880	38720	58080	75020	89540	137940	191180
		M^2(per Km)	0.75	2.121	2.371	2.598	2.806	3	3.674	4.175	4.562	5.662	6.666
0.527	4	P_{reach} (Watt)	2030	16240	20300	24360	28240	32480	48720	62930	75110	115710	160370
		M^2(per Km)	1	2.828	3.162	3.464	3.741	4	4.898	5.567	6.082	7.549	8.888
0.163	10	P_{reach} (Watt)	1310	10480	13100	15720	18340	20960	31440	40610	48470	74670	103490
		M^2(per Km)	2.5	7.071	7.905	8.660	9.354	10	12.247	13.919	15.206	18.874	22.220
0.116	14	P_{reach} (Watt)	940	7520	9400	11280	13160	15040	22560	29140	34780	53580	74260
		M^2(per Km)	3.5	9.899	11.067	12.12	13.09	14	17.146	19.487	21.289	26.424	31.108

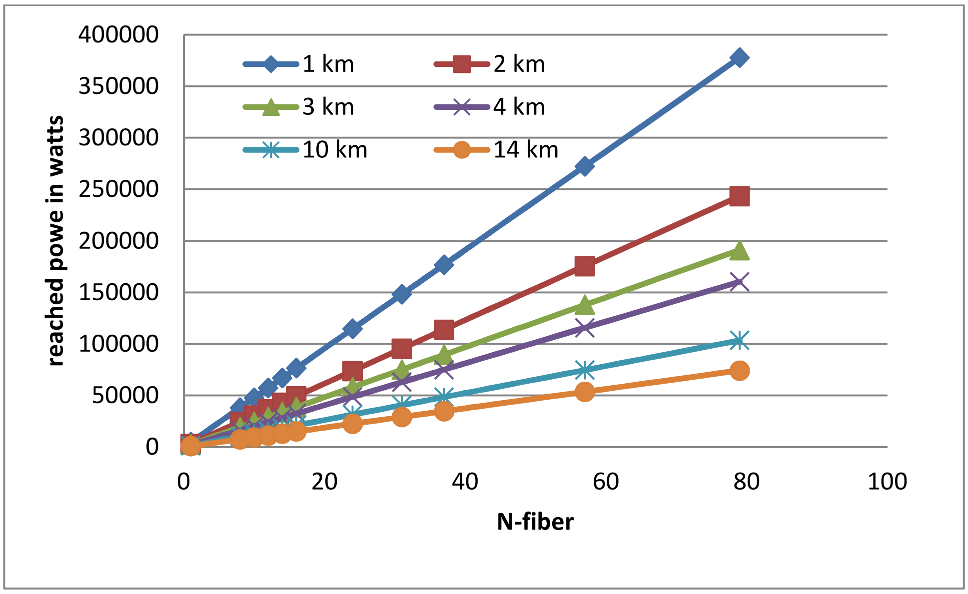

Fig (2): Show the reached power is directly related to the N - fiber of FLWS and inversely proportional to the range.

In this paper, the number of incoherent fiber lasers of FLWS consists of 16-fiber (10 kW/fiber), at the range a few km and have a beam director radius of ~20cm as shown in Fig (3).

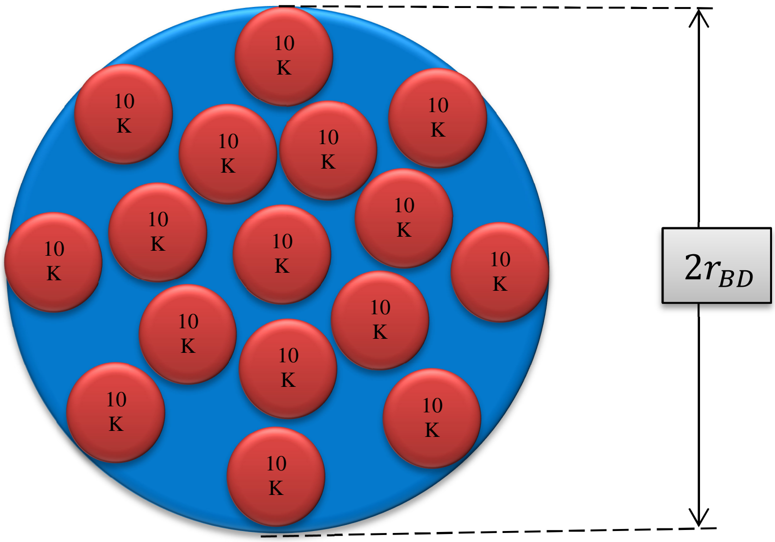

Fig (3): The Cross section of 16-fiber beam director with a beam director radius of ~20cm.

It is obvious that the level of power reaching to target varies considerably depending on the R_{FLWS}, μ and reflectivity of skin. Fig (4) shows the power reaching of 16-fiber system is decreasing when increase the range of targets as a result the atmospheric attenuation coefficient μ of the laser beam. A scattering of atmospheric species causes attenuation to the FLWS beam, Fig (5) shows the atmospheric Attenuation as an exponential function of range. The reached power of FLWS decreases to 1/e of its original value.

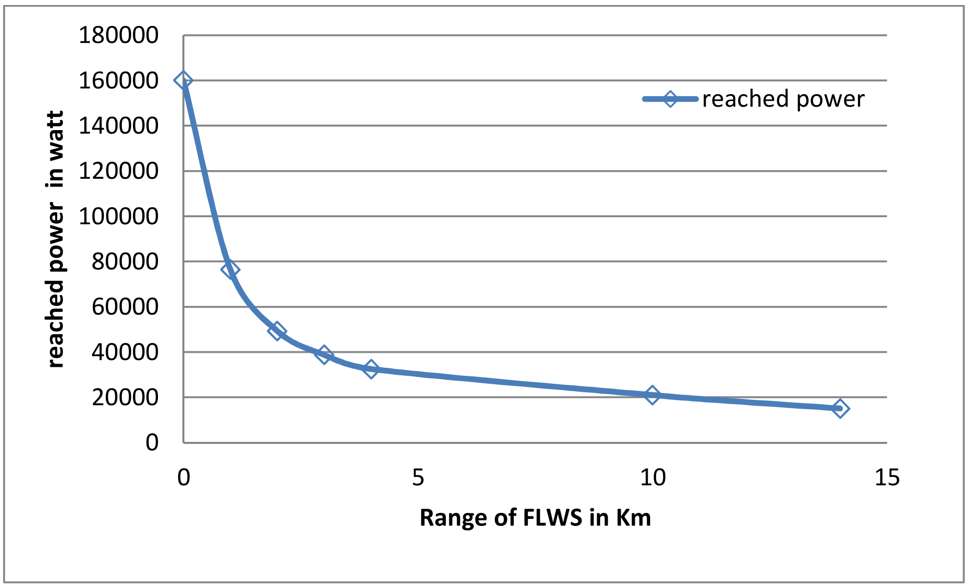

Fig (4): Show the power reaching of 16-fiber system is decreasing (as exponential) when increases the range.

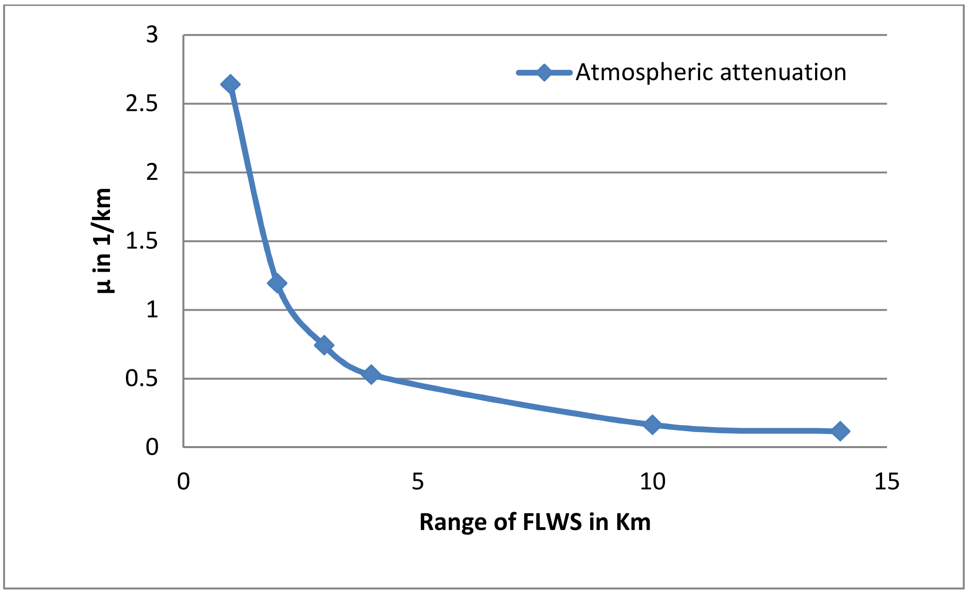

Fig (5) shows the atmospheric Attenuation as an exponential function of range.

It can be concluded from Fig (6), the quality of beam directory proportional directly with number of fiber and R_{FLWS}. Where the high values of (M^2) lead to an increase in the beam divergence θ_d and focused spot size.

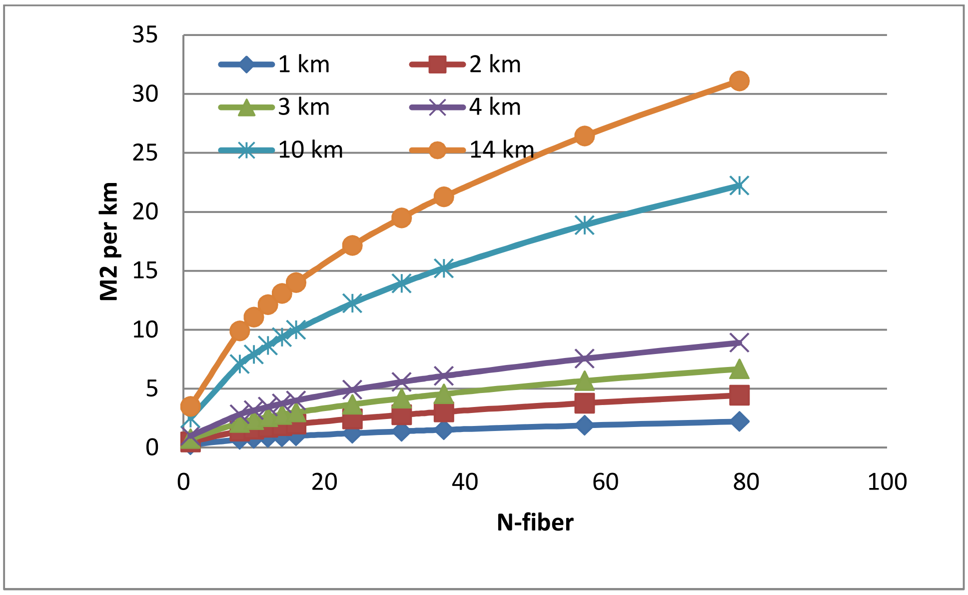

Fig (6): the quality of beam directory proportional directly with number of fiber and R_{FLWS}

According to these results, the effective range of FLWS, must be no more than a few kilometers in order to avoid losses resulting from the spread of the laser beam through the atmosphere. For example, at range 14 km with incoherent fiber laser N-fiber = 79, the power output from FLWS Energy up to 790000 watts, but only 74260 watts reach to the target (i.e. Loss in the amount of power about 715740 watts, which is a great loss compared with the classical weapons).

However, the FLSWR can burn a hole through the skin of targets; aircraft with wet wings are doomed and similarly fuel cells, which are not protected by large amounts of airframe structure. The damage can be done with power less than threshold power.

Also the threshold Power depends on the finish skin of the target. For example, the painted area has significantly increased energy absorption compared with the steel plate unpainted. Where the both reflective and absorption processes are varies widely depending on materials and different wavelengths of laser.

The FLWS designed to shoot down aircraft, helicopters and missiles or any target moving at high velocity (as shown in Table 1). Therefor the FLWS must have the ability to maintain a very strong beam at one small area (a few cm2) on the target for long enough time (5 Sec) to deliver at least 18371 J/cm^2. On the other hand, the target parts such as optical sensors and electronic circuits are much easier to damage and therefore we need much less power than the threshold power.

4.Conclusion

- The effectiveness of the FLWS to cause mechanical damage is, therefore, depends on the reached power, atmosphere attenuation, targets materials, reflectivity of the surface, pulse duration, wavelength, and air pressure.
- The combining fiber laser can lead to higher power, highly efficient, compact and low maintenance.
- The power from FLWs must be focused on the target long enough for the skin material to absorb the radiation.
- The quality beam of threshold power is inversely proportional to M^2 factor, N-fiber and RFLWS.
- Laser weapons are currently in the early stages, much of the research to be done before that up to the required level.

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