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P5_1 Genius, Billionaire... Energy weapon?

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Abstract

This paper investigates the minimum power output required for Iron Man to completely destroy Winter Soldier's cybernetic arm in the film "Captain America: Civil War". This was quantified as 2.84 GW, demonstrating that the Mark 46 suit dwarfs the power output of the current strongest direct-energy weapon in the world (MK2 MOD 0) by almost a factor of 19,000.

Introduction

In the film "Captain America: Civil War" [1], Iron Man, sporting his Mark 46 armour, destroys Winter Soldier's titanium cybernetic arm using his 'Unibeam', a particle-beam weapon, at the HYDRA Siberian Facility. This paper will examine the minimum power output required to destroy Winter Soldier's cybernetic arm and since particle-beam weapons are yet to exist in service, it will be compared to the world's most powerful direct-energy weapon (DEW)

Assumptions

The arm itself will be considered as two conical cylinders, one from the shoulder joint to the elbow, and the other from the elbow to the fingertips. The dimensions of a replica arm can be used to calculate the volume the cybernetic arm [2]. In the film, the strength and durability of the arm was quite impressive, so we will assume that it comprises Titanium Grade 5 alloy (Ti-6Al-4V) of uniform density, $\rho_{Ti(5)} = 4429$ kg m^{-3} [3]. The fight took place in a Siberian facility, so the upper limit to the average temperature in January within central Siberia, will be taken as the ambient temperature, T_{amb} = -10°C [4].

Theory

Since the arm was entirely destroyed, the energy required to vapourise the arm will be found and thus the power of the 'Unibeam'. The fight takes place in an area exposed to the outdoors, so the cybernetic arm would have cooled down to the ambient temperature, T_{amb}. We begin by stating the volume of a conical section,

$$V = \left(\frac{\pi h}{3}\right)(R^2 + Rr + r^2) \tag{1}$$

where h is the height of the cylinder, R is the larger base radius, and r is the smaller base radius. From this, the volumes of the upper arm and the forearm can be calculated respectively,

$$V_{arm} = V_1 + V_2 = \left(\frac{\pi}{3}\right)\Big[h_1(R_1^2 + R_1 r_1 + r_1^2) + h_2(R_2^2 + R_2 r_2 + r_2^2)\Big] \tag{2}$$

where the upper arm dimensions are h_1=24 cm, R_1=6.75 cm, r_1=6.50 cm, and the forearm dimensions are h_2=51 cm, R_2=7 cm, r_2=6 cm.

As uniform density is assumed, the mass of the arm can then be found

$$m_{arm} = \rho_{Ti(5)} V_{arm}. \tag{3}$$

The vapourisation of Titanium requires enough energy to overcome the transition thresholds, in addition to its internal kinetic energy.

$$E = mc_p\Delta T + m(L_f + L_v) \quad (4)$$

There is no data at temperatures above the melting point of the alloy, therefore, a model of pure Titanium will be used, since the differences between them are quite negligible at temperatures above 1800 Kelvin. Hence, using equation (3), the energy required for vapourisation from a solid state is

$$\begin{aligned} E_v = m_{arm}(c_{p_{Ti(5)}}(T_{f_{Ti(5)}} - T_{amb}) \\ + L_{f_{Ti(5)}} + c_{p_{Ti}}(T_{v_{Ti}} - T_{f_{Ti(5)}}) + L_{v_{Ti}}) \end{aligned} \quad (5)$$

where for the Titanium alloy, the mass of the arm is m_{arm}, the specific heat capacity, $c_{p_{Ti(5)}}$=0.5263 J/g°C [5], the melting point ranges between 1606-1660°C [5] and the latent heat of fusion ranges between 360-370 kJ kg^{-1} [3], so, to produce the minimum energy required, $T_{f_{Ti(5)}}$=1660°C and $L_{f_{Ti(5)}}$=360 kJ kg^{-1} respectively. For pure Titanium above 500 K, the specific heat capacity, $c_{p_{Ti}}$= 0.6072 J g^{-1} °C^{-1}, the boiling point, $T_{v_{Ti}}$=3260°C and the latent heat of vapourisation, $L_{v_{Ti}}$=9.83 MJ kg^{-1} [6].

Using the 'Unibeam's' pulse duration, the minimum power output of Iron man is

$$P_{beam} = E_v/t_{pulse}. \quad (6)$$

Results

Using equation (2), the volume of the upper arm, V_1=3.309×10^{-3} m^{-3} and the volume of the forearm, V_2=6.782×10^{-3} m^{-3}, which gives the total volume of the cybernetic arm is V=0.01 m^{-3}. Using equation (3), the mass of the cybernetic arm, m_{arm} = 44.29 kg. Using equation (5), the required energy for vapourising the arm is 533 MJ. The pulse duration of the 'Unibeam' was measured as 0.1875s in the film, thus, using equation (6), the power required to vapourise this particular mass of Titanium Grade 5 alloy is 2.84 GW.

Discussion and Conclusion

The minimum power required by Iron Man to destroy the cybernetic arm was found to be 2.84 GW. Since, the outputted power is not produced instantaneously, but taken from stored charge, the power of the beam does not reflect the power of reactor. Even with modern advancements of DEWs, where Lockheed Martin's ATHENA, capable of firing 30 kW beams, broke the record for the most powerful DEW in 2017 [7] and then the MK 2 MOD 0 LWSD aboard the USS Portland, capable of outputting a 150kW beam [8], breaking the record in 2020, the minimum power of the 'Unibeam' calculated in this paper is still almost 19,000 times higher than the latter.
So having a weapon capable of vapourising tough metal objects may still be a work of fiction in our lifetime.

References

[1] Feige, K [Producer], Russo, A; Russo, J [Directors], 2016, Captain America: Civil War [Film], Walt Disney Studios

[2] `https://www.aliexpress.com/item/32861998959.html` [Accessed 11 October 2021]

[3] `https://www.azom.com/properties.aspx?ArticleID=1547` [Accessed 11 October 2021]

[4] `https://www.climatestotravel.com/climate/siberia` [Accessed 10 October 2021]

[5] `http://asm.matweb.com/search/SpecificMaterial.asp?bassnum=MTP642` [Accessed 11 October 2021]

[6] `https://espimetals.com/index.php/technical-data/254-Titanium` [Accessed 11 October 2021]

[7] `https://www.zmescience.com/research/technology/most-powerful-laser-weapon-9634654/` [Accessed 12 October 2021]

[8] `https://www.popularmechanics.com/military/navy-ships/a32676643/navy-laser-weapon-system-demonstrator-test/` [Accessed 21 October 2021]