Table of Contents

1. Which robots are affected? 1
2. Why limit the kinetic energy of robot weapons? 1
3. What are the specific conditions for robots to compete in Makerfight? 2
4. Definitions: 3
   a) Translational kinetic energy 3
   b) Rotational kinetic energy 3
5. Orders of magnitude 4
6. In practice 6
   a) What formula should be used to calculate kinetic energy? 6
   b) How do you determine the moment of inertia I 6
   c) How do you determine the speed w 8
   d) Calculate the kinetic energy Ec 10
   e) What should be done if the kinetic energy of the weapon exceeds the permitted limit? 10
   f) Need help? 11

1. Which robots are affected?

All robots with a non-strictly cylindrical part rotating outside the robot (examples: vertical spinners, horizontal spinners, drum spinners, shell spinners, full body spinners, bar spinners).

This also applies to robots that are not strictly cylindrical in shape and whose main attack principle is to rotate on themselves (example: metly brain).

2. Why limit the kinetic energy of robot weapons?

The kinetic energy contained in the weapon of a combat robot can be dissipated in several ways:

Either the motor is slowed down or even stopped, and this energy is dissipated by friction (and/or heating of the motor controller, and/or transmitted back to the battery via the motor controller).

Or the weapon collides with an object (either an opposing robot or the arena).

In the latter case, all or part of the energy contained in the inertial weapon will be transmitted, half to the robot carrying the weapon and half to the other object (either the opposing robot or the arena).

⇨ ***The arena must be able to absorb the energy transmitted by a direct collision with an inertial weapon through deformation, regardless of the amount of energy contained in the weapon.***

As for the two robots, if they still contain energy (after any deformation of the robot(s)), they will tend to move under the effect of this energy.

If the direction of movement includes a vertical component (for example, a robot moves upwards), the amount of energy it contains will decrease due to gravity.

If the direction of movement includes a horizontal component, the amount of energy will potentially decrease due to friction between the robot and the ground.

In all cases, the arena can be and will often be the obstacle that will have to stop the movement of the robot(s).

⇨ ***The arena must be able to absorb, through deformation, the energy transmitted by a collision with a moving robot, regardless of the direction of movement, the position of the point of impact, and the amount of energy contained in the robot.***

To prevent the arena from breaking, which would endanger the public, participants, and organizers, and given that the arena has its own mechanical limits, the only solution to ensure people's safety is to limit the amount of kinetic energy that an inertial weapon can contain to a value that the arena can withstand without breaking.

3. What are the specific requirements for robots to compete in Makerfight?

- If your robot is affected by the limitation, you must provide Makerfight with a document explaining how you performed the calculations several days before the tournament (number of days to be determined). It must include the formulas used, the input data, and the output data. It is advisable to attach screenshots, photos, and excerpts from technical data sheets. The document must provide sufficient information to enable the organizers to validate the calculations.
  If you fail to do so, you may not be able to compete.

- The speed of the weapons will be measured during the tech check to validate that your robot complies with the kinetic energy limit. If your robot exceeds this limit, you will be asked to take the necessary measures. If you are unable to bring your robot into compliance with this rule, you will not be able to compete.

- Speed measurements may be taken throughout the weekend, either randomly, systematically, or in case of doubt. If your robot exceeds the limit during a check, you will be immediately excluded from the event.

4. Definitions:

Kinetic energy is a fundamental concept in physics, particularly in dynamics.

Like all energy, kinetic energy is expressed in joules (J).

The kinetic energy of a system is the sum of the kinetic energies of the bodies that compose it. There are two forms of kinetic energy:

a) Translational kinetic energy

In the case of a body in translation, with mass m and velocity v, the kinetic energy E_c is proportional to the mass of the body and the square of its velocity, i.e., the relationship:

$$E_c = \frac{1}{2} m v^2$$

where:

- Ec: kinetic energy in joules $[J]$
- m: the mass in kilograms $[kg]$
- v: the velocity in meters per second: $[m \cdot s{-1}]$

b) Rotational kinetic energy

In the case of a rotating body, kinetic energy is proportional to the square of the angular velocity ω, according to the relationship:

$$E_c = \frac{1}{2} I \omega^2$$

- Ec: rotational kinetic energy in joules $[J]$
- I: moment of inertia in $kg \cdot m2$ relative to the axis of rotation
- w: the rotational speed in rad/s

Sources:

Larousse: https://www.larousse.fr/encyclopedie/divers/%C3%A9nergie_cin%C3%A9tique/187136

Lycée Jean Monet de ANNEMASSE: http://sa.ge.sts.free.fr/Wiki/pmwiki.php?n=SA.SolideEc

5. Orders of magnitude

Below is a comparison between the kinetic energy contained in bullets from certain firearms and that contained in the kinetic energy weapons of certain robots, most of which are featherweight and therefore eligible to compete in Makerfight:

.22LR revolver bullet: 200J (0.2KJ)

.357 Magnum revolver bullet: 796J (0.796KJ)

M43 AK47 Kalashnikov bullet: 2400J (2.4KJ)

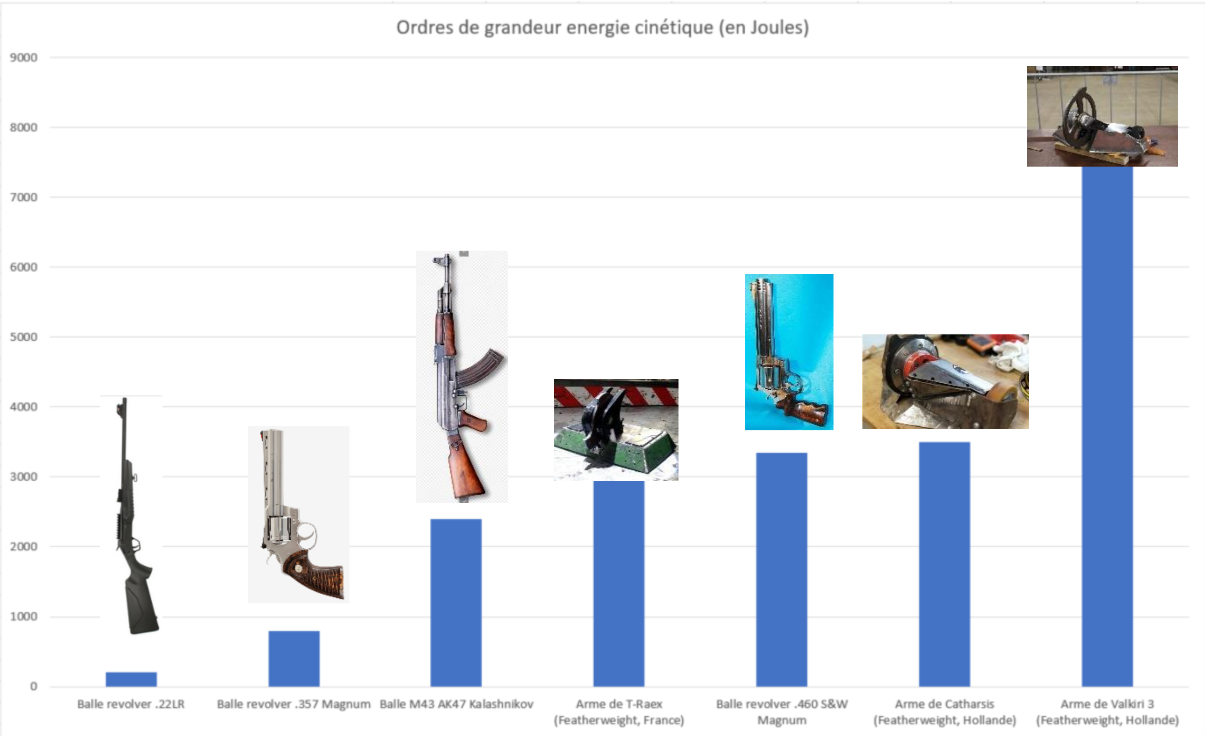
T-Raex weapon (Featherweight, France): 3250J (3.25KJ)

.460 S&W Magnum revolver bullet: 3340J (3.34KJ)

Catharsis weapon (Featherweight, Holland): 3800J (3.8KJ)

Valkiri 3 weapon (Featherweight, Holland): 7800J (7.8KJ)

Tombstone's weapon (Heavyweight, USA): 103000J (103KJ) – not shown in the chart below.



Sources:

Wikipedia:

https://fr.wikipedia.org/wiki/9_mm_IMI

https://fr.wikipedia.org/wiki/7,62_%C3%97_39_mm_M43

Ray Billings (Tombstone Builder) YouTube:

https://www.youtube.com/watch?v=BVvdNLw0aw0&t=45s

The values for the Catharsis, T-Raex and Valkiri 3 weapons were found on the European combat robot builder Discord (https://discord.gg/m4zhncj9dh), or through written exchanges.

6. In practice

a) What formula should be used to calculate kinetic energy?

Here we consider the case of rotation, so the formula is:

$$E_c = \frac{1}{2} I \omega^2$$

- Ec: the kinetic energy of rotation in Joules $[J]$
- I: the moment of inertia in kg·m2 relative to the axis of rotation
- ω: the rotational speed in rad/s

b) How to determine the moment of inertia I

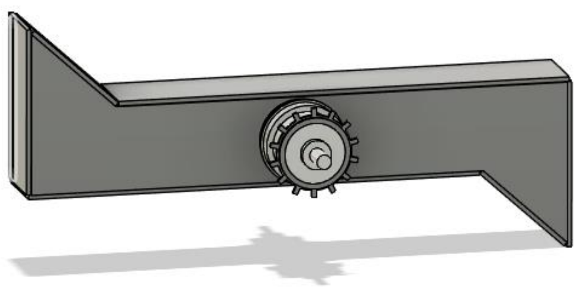
First, isolate the weapon and determine all the rotating parts related to that weapon.

For robots whose main attack principle is to rotate on themselves, the entire robot must be considered.

You must have a CAD model of the whole robot and know either the weight of each part or the material it is made of.

Ensure that the weight of the modeled parts corresponds to the weight of the actual parts.

Practical example:



Note:

The kinetic energy of the motor and transmission is deliberately neglected, partly because it generally has little influence on the final result, and partly to simplify the calculations.

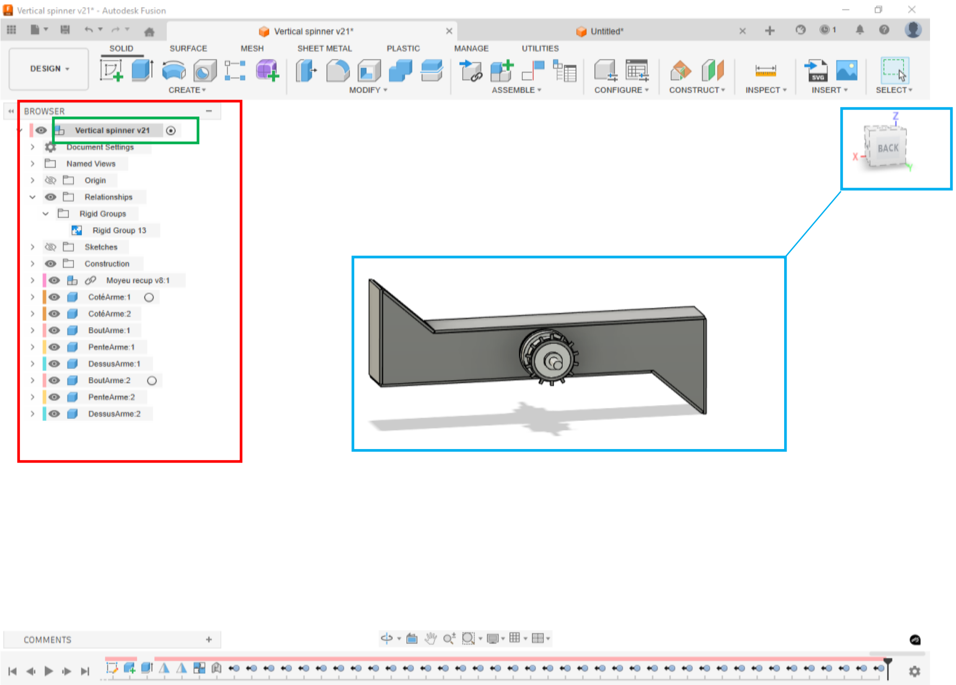
Moment of inertia of the weapon:

Example using Fusion 360 software:

Note that:

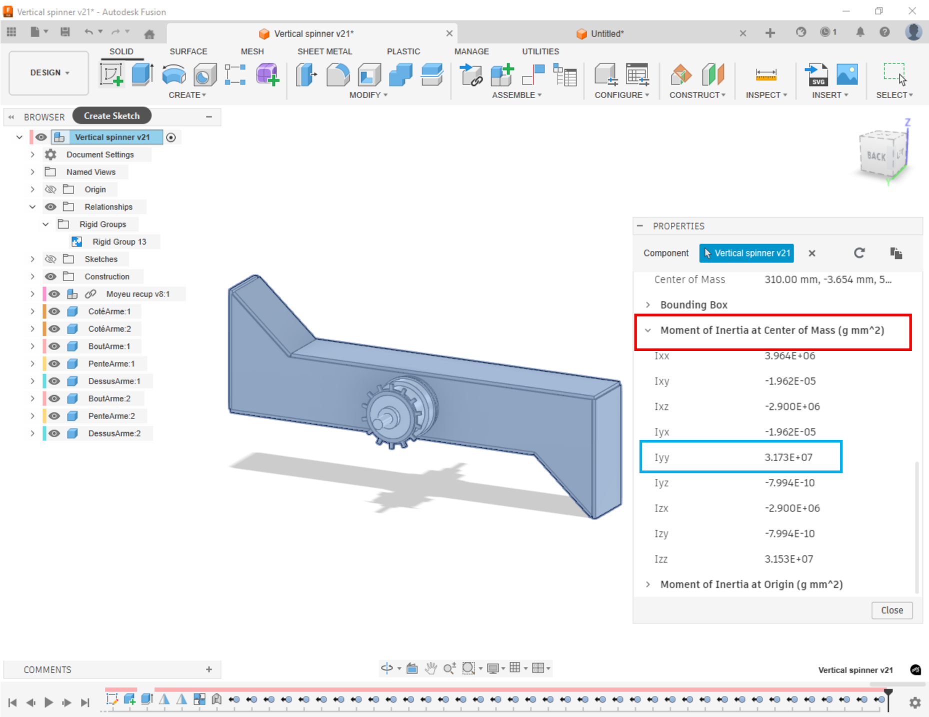
The file must only contain the parts to be considered (you can make a copy of a file and then use the right-click command and Remove on the other parts, for example).

In our case, the part rotates around the Y axis.



Right-click on the document (here on Vertical spinner v21), then on Properties.

In the properties, select Moment of inertia at center of mass (g mm²).



Note the value Iyy (because the part rotates around the Y axis).

However, the value given is not necessarily immediately meaningful: 3.173E +07

You can use the Windows calculator:

Key 7

Key **10^x**

⇨ The calculator displays 10,000,000

Press *

Type 3.173

= key

Result: 31,730,000

All that remains is to convert these g mm² into kg m².

To do this, divide the value by 1,000,000,000.

Moment of inertia I = value in g mm² / 1,000,000,000

= 31,730,000 / 1,000,000,000

= 0.03173 kg m²

c) How to determine the speed w

First, determine the motor speed. There are two possible methods: measurement or theoretical calculation.

Determining the motor speed by measurement

This method requires a motor measurement tool called a tachometer.

These devices allow measurements to be taken in different ways; refer to the user manual.

In all cases, the measurement must be taken on the motor that will be used in the robot, with the battery that will be used in the robot charged.

In the case of a DC motor (usually 2 wires), it is possible to connect it directly to the battery, or to go through the ESC (Electronic Speed Controller) that will control it in the robot.

In the case of a 3-wire servo (or brushless) motor, there is no choice but to use the ESC.

If using an ESC, you will first need to:

- Wired the ESC to the radio receiver
- Paired (binder) the radio receiver and remote control
- Configured everything correctly

In all cases, you must measure the speed in revolutions per minute (rpm).

Determining motor speed by theoretical calculation

First, either measure the voltage of the battery once it is charged, or determine it.

Example for a LiPo battery: Each cell is worth 4.2V. For a 6-cell battery (6S), the voltage = 6 * 4.2 = 25.2V

Next, you need to find the voltage/speed ratio of the motor.

For a DC motor: looking in the motor's technical specifications, we find:

Nominal speed: 3200 rpm

Nominal voltage: 24VDC

Ratio = Nominal speed / Nominal voltage

= 3200 / 24

= 133.3 rpm/V

We can therefore calculate the speed of the motor when powered by the charged battery:

Speed = Voltage * ratio

= 25.2 * 133.3

= 3359.16 rpm

For a servo (or brushless) motor with 3 wires, the ratio is usually indicated directly under the name KV.

Example KV = 140

We can therefore calculate the speed of the motor when powered by the charged battery:

Speed = Voltage * ratio

= 25.2 * 140

= 3528 rpm

Calculating the rotation speed of the weapon

In the case of a toothed belt or chain, you need to know the number of teeth on the drive sprocket (e.g., 16) and the number of teeth on the driven sprocket (e.g., 32).

Weapon speed = motor speed * (number of teeth on the drive sprocket / number of teeth on the driven sprocket)

= 3528 * (16/32)

= 3528 * 0.5

= 1764 rpm

In the case of a non-toothed belt, you need to know the pitch diameter of the drive pulley (e.g., 50 mm) and that of the receiver pulley (e.g., 75 mm).

Weapon speed = motor speed * (pitch diameter of the drive pulley / pitch diameter of the driven pulley)

= 3528 * (50/75)

= 3528 * 0.666

= 2349.648 rpm

The speed must then be converted from rpm to rad/sec.

Example:

Speed rad/s = speed in rpm * 2 * π / 60

= 1764 * 2 x π / 60

= 184.7 rad/s

d) Calculate kinetic energy Ec

$$E_c = \frac{1}{2} I \omega^2$$

Let's take an example where I = 0.03173 kg m^2 and ω = 184.7 rad/s

Kinetic energy Ec = ½ * 0.03173 * 184.7^2

= 0.5 * 0.03173 * 184.7 * 184.7

= 541.22003785 J

= 0.54122 kJ

e) What should be done if the kinetic energy of the weapon exceeds the permitted limit?

As a general rule, this problem can be easily solved by limiting the speed of the motor. This function can often be performed via the remote control, which has options for limiting the value of an output channel, in this case that of the weapon.

Let's take an example:

I = 0.7 kg/m^2

ω = 132 rad/s

Kinetic energy Ec = ½ * 0.7 * 132^2

= 0.5 * 0.7 * 132 * 132

= 6098.4 J

Limit = 2,000 J

This value of Ec is considered if the motor can reach 100% of its speed.

To what percentage of speed must the motor be throttled in order to comply with the limit?

Ratio = (ROOT(Limit / (1/2 * I)) / w

= (ROOT(2000 / (0.5 * 0.7)) / 132

= 0.5726

Percentage = Ratio * 100

= 0.5726 * 100

= 57.26%

If we do the reverse calculation, with w = 132 * 0.5726 = 75.5832 rad/s

Kinetic energy Ec = ½ * 0.7 * 75.5832^2

= 0.5 * 0.7 * 75.5832 * 75.5832

= 1999.487042784 J

- ⇨ The motor speed can therefore be limited to 57.26% of its maximum to comply with the authorized limit.

If, on the other hand, the motor is not controlled by an ESC but, for example, by a relay (DC motor only), the following options should be considered:

By adjusting the speed (the simplest option, in principle):

- Change the transmission ratio between the motor and the weapon
- Change the voltage (and therefore the battery)
- Replace the relay with an ESC

By adjusting the moment of inertia:

- Modify the geometry of the weapon

f) Need help?

Does all this seem too complicated, or do you not have CAD software or a way to measure the motor speed? Don't panic!

You can, in order:

1) Look around for someone who can help you do it
2) Ask for help on the Discord channel "European combat robot builder" (https://discord.gg/m4zhncj9dh)
3) Come to Technistub with your parts (reserved for members who are up to date with their membership fees)
4) Contact eric@makerfight.fr