Problem Set 4: Uniform Circular Motion

Design Engineering Challenge: "The Big Dig" 2.007 Contest
Platter Strategies: Ball Liberation

Overall Notes: You are not required to perform the actual analysis in this problem set, as they will do some example analysis on the next problem set. In this problem set, you should consider each of the various possibilities and determine what physic principles are required to solve the problem. For each question, you should describe the physics in words to show a physical understanding of the problem, as well as note simple free body diagrams and the important equations. Two examples of good drawings and a few sets of supplemental equations are shown in this solution. The remainder of the answers given in the solution are descriptions of the important physics, with some "real world" 2.007 considerations added in. You may have a solution that is not listed in this "solution," which is perfectly acceptable, as long as you can justify it in the future!

PROBLEM 1: Methods to liberate shot put without touching them

By centrifugal action:

Rotate the platter until the centrifugal force on the shot puts is large enough to dislodge them.

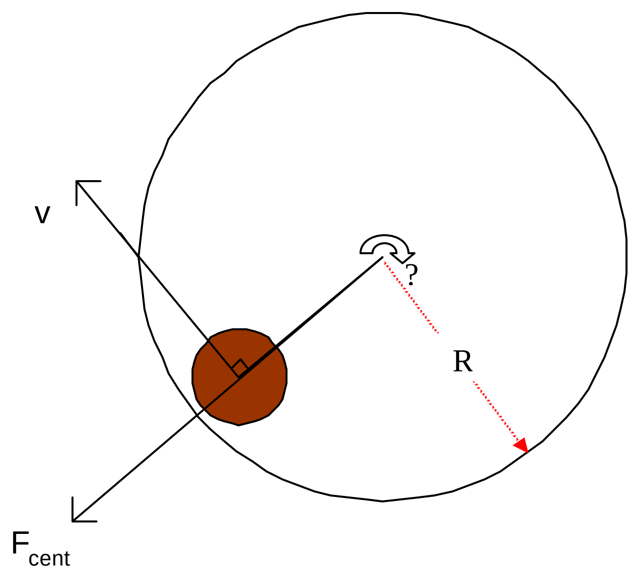

Figure 1: Sketch of a particle rotating at a speed ?

Where,

m: mass of particle

v: tangential speed of particle

? : angular speed of particle

a_{radial}: radial acceleration

F_{cent}: centrifugal force acting on the mass particle in the radial direction r: Radius from center of rotation to center of particle

$$v = w \times r$$

$$a_{radial} = \frac{v^2}{r}$$

$$F_{cent} = m * a_{radial} = m * \frac{v^2}{r}$$

To liberate a shot put, F_{cent} must be greater than the force required to dislodge it, which you will analyze in the next problem set. Another consideration is the torque required to accelerate the platter up to the required rotational velocity ? (uses the rotational version of F = m*a, $\Gamma = I * a$). The inertia I is composed of the platter and the shot puts, while the inertia of the hockey balls can be considered less than the other items.

After the shot puts are on the ground, the car can acquire the shot puts using several different strategies. Possible strategies for acquiring the balls include picking them up with a shovel, rolling them onto the machine using a ramp, or other mechanisms to load the shot puts onto the machine's body. If the machine will roll the shot puts to the scoring bin, then a shovel or some form of controlling structure is needed.

By impacting the platter:

Hit the platter with the vehicle so as to impart energy to the shot-puts. This energy must be high enough to dislodge them. Physics of impact and collision will have to be considered. This strategy is risky as it may damage the table or the machine.

By vibrating the platter:

Shake the platter at a high frequency to incrementally impart energy to the shot-puts until it is high enough to dislodge them. Physics of vibration and collision will need to be considered. The platter can be vibrated by hitting it or spinning it back and forth.

PROBLEM 2: Methods to liberate shot put by touching them

By pushing the shot-puts:

Fix the rotating platter and hit the shot put using an arm or some feature of the machine. Physics of this strategy are simple force and moment balances, as well as a consideration of energy available. To rotate an arm with sufficient torque to push a heavy shot-put may require more powerful motors then the ones used in the 2.007 competition.

By applying a direct impact force:

This can be achieved by means of a plunger, projectile, or a swinging arm. This strategy is a difficult strategy to employ, as it requires a large force at high velocity to dislodge the shot put and requires the machine to precisely aim the striking mechanism. The physics involved in this strategy include force and moment balance, impact and momentum and energy principles.

By ramming the shot-puts with the machine:

While deploying a projectile or swinging arm can be difficult, a super simple method of impacting a large force into the balls on the platter is to ram them with a machine. In this case, similar physics to the previous case must be considered. In addition, the ramming momentum must be calculated based on how fast the machine is moving when it hits the shot puts. This momentum is based on acceleration of the car over the distance it has traveled combined with the total mass being accelerated.

By grabbing the shot-put while on the platter then lifting it:

This strategy would require an analysis based on work and energy principles, as well as a moment balance to ensure that the car doesn't tip. Also, concepts such as friction and slipping will need to be considered. In a real world sense, this strategy can require complicated mechanism. While the Keep It Super Simple (KISS) principle says this may not be a good strategy, it shouldn't be thrown away immediately.

PROBLEM 3: Methods to liberate the hockey balls without touching them

The same strategies used for problem one apply when liberating the hockey balls. However, the hockey balls are much lighter; hence much less energy is required to liberate the hockey balls compared to the shot puts.

Since it takes much less energy to spin the hockey balls loose, it would be easier to spin the platter and send the balls flying. However, you still have to consider the shot puts! Either you must remove them first or include them in the calculations. When trying to remove the shot puts by centrifugal action, the hockey balls can mostly be disregarded since their inertia is much smaller than the shot puts. When trying to remove the hockey balls, the shot puts still represent more inertia to accelerate, unless they have been removed. In both cases, the torque required to accelerate the disk must include the inertia of both the hockey balls and the shot puts. The crucial difference between the two cases is the time required to accelerate the platter to the velocity at which the balls or shot puts pop out of their hole.

PROBLEM 4: Methods to liberate hockey balls by touching them

The same strategies used for problem two apply when liberating the hockey balls. However, the hockey balls are much lighter; hence less energy is required to liberate the hockey balls compared to the shot puts.

For the hockey balls, the energy required to acquire the balls is much less. Strategies such as lifting shovels and plows are much more likely to work successfully.

PROBLEM 5: What do you think is the best strategy?

There are many strategies that can be defined as "best" if a logical analysis has been made. Proper justification must be made for whatever strategy is selected. Your solution should include a weighted selection chart of the different strategies.

One good strategy is to push the shot puts off the platter then spin the platter to get the hockey balls. Experiments are needed to check what forces and speeds are needed to liberate them by just spinning the wheel. An analysis of power and energy available in the system (called a Power Budget) is required to make sure that your motors can supply sufficient force at the required speed.

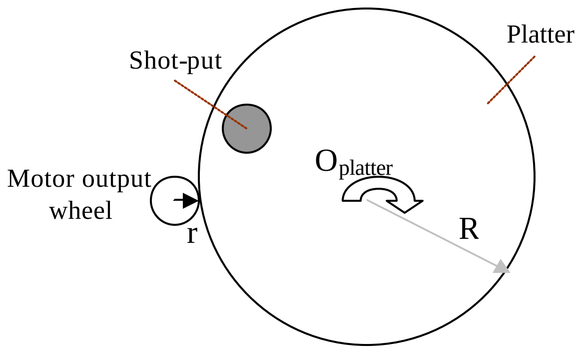

Figure 2: sketch of shot-put on the rotating platter

A simple analysis to get a feel of the power in the system can be performed. (Power calculations aren't required in this problem set!! This is simply to better your understanding of a design problem.)

P_{in}: Power input by the motor
P_{out}: Power to the platter

Assume no friction or any other losses in the system

$$\Rightarrow P_{out} = P_{in}$$

$$\Rightarrow \Omega_{platter}{}^{2} R = w_{motor}^{2} r$$

Checking the 2.007 website from last year one can get estimate values for the angular speeds for the Tamiya motors used. $R_{platter}$ is a given and you can design for r to get the $O_{platter}$ required to generate enough centrifugal force to push out the pucks. Values for the centrifugal forces will be discussed in the next problem set.