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"Concentric drum" project strategy research - Ideal drum model at arbitrary tension Angle

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Abstract: Based on the impact motion theory and rigid body motion theory of theoretical mechanics, this paper conducts a theoretical analysis on the project of "concentric drum". The motion of the drum is divided into two stages of drum pulling and ball touching, and then the dynamics analysis is carried out in turn to establish an ideal drum pulling model under any tension Angle.
Keywords: Law of rigid body motion; Theoretical mechanics; Ideal drum model.

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1. THE PRINCIPLE OF CENTRIPETAL COLLISION

In the "concentric drum" project, the collision between the drum and the ball directly affects the height of the bouncing ball. The collision motion theory in theoretical mechanics can solve this kind of collision well and help us determine the optimal strategy of the project.

Let's say that the masses are m_1 and m_2 two objects A and B,a collision with the center occurs (Figure 1), The velocity before the collision is $\boldsymbol{v}_1$ and $\boldsymbol{v}_2$, respectively The velocity after the collision is $\boldsymbol{u}_1$ and $\boldsymbol{u}_2$, Since the collision time is extremely short, it is assumed that the system composed of ball and drum in the collision process satisfies the law of momentum conservation

$$m_1\boldsymbol{v}_1 + m_2\boldsymbol{v}_2 = m_1\boldsymbol{u}_1 + m_2\boldsymbol{u}_2. \tag{1}$$

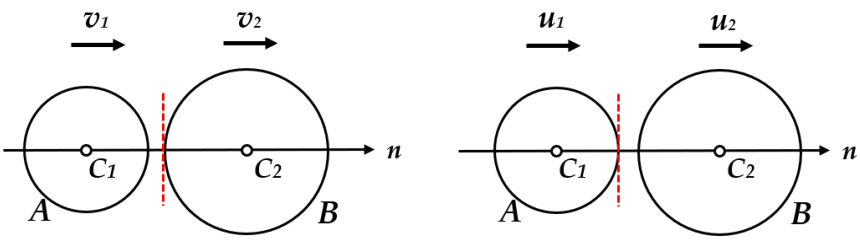

Figure 1. Centroid collisions between objects

Newton summarized the results of a large number of collision experiments, introducing the recovery coefficient [3]

$$e = \left|\frac{u_2 - u_1}{v_2 - v_1}\right| \tag{2}$$

To measure the rate of energy loss in elastic collisions. When $e = 1$ it is a completely elastic collision,, when $e = 0$ it is a completely inelastic collision, when $e \in (0,1)$ it is an incompletely elastic collision, the value of recovery coefficient E is related to the material of the colliding object [4]. By means of the recovery coefficient e, we can determine the velocity of the two objects at the end of the collision::

$$\begin{cases} u_1 = \dfrac{(m_1 - em_2)v_1 + m_2(1+e)v_2}{m_1 + m_2} \\ u_2 = \dfrac{(m_2 - em_1)v_2 + m_1(1+e)v_1}{m_1 + m_2} \end{cases} \tag{3}$$

In this formula, the velocity direction of object A and B is set the same before and after the collision. In the laboratory, the method of collision between an object and a fixed surface($m_2 \to \infty$) is often used to determine the recovery coefficient e. .If object A is free falling from height h_1 with no initial velocity release,free fall to collision with the horizontal fixed surface, after the collision to jump back to height h_2 , there are $v_1 = \sqrt{2gh_1}$ and $u_1 = \sqrt{2gh_2}$, So let's do that by the formula

$$e = \frac{u_1}{v_1} = \sqrt{\frac{h_2}{h_1}} \tag{4}$$

Measure the value of the recovery coefficient e.

It is stipulated in [1][2], that the rebound height of no. 5 volleyball (adult volleyball) used in competition at a height of 1800 mm should be between 1100 mm and 1400 mm, and the recovery coefficient of standard volleyball should be calculated by formula (4), and its value should be between 0.7817 and 0.8819.For the convenience of calculation, we take the mean value e=0.8318 as the recovery coefficient of the volleyball.

2. THE ESTABLISHMENT OF IDEAL DRUM MODEL

2.1 Analysis

Figure 2, we are in A single fixed point of the drum motion of force analysis.. Set the initial point of the rope OAinitial Angle of θ with the ground , in the end of the rope on A direction parallel to the $\overrightarrow{AB}$(with horizontal tilt Angle α), the size is equal to the constant force F, the ends of the rope pulled from point A to point B. We can determine the appropriate direction and intensity of the force with the goal of the best cooperative strategy.

To make the team make the best coordination strategy, the height of the bouncing ball should be higher than the specified base height, but not too high, otherwise it will increase the difficulty of the next shot. Therefore, the stability of the bouncing ball height with respect to included Angle is an important indicator.Ideally, if everyone is hitting the ball at the same time, the drum would go straight up without tilting, and the ball would hit right in the center of the drum, so that the ball would not end the program if it deviated from the drum.

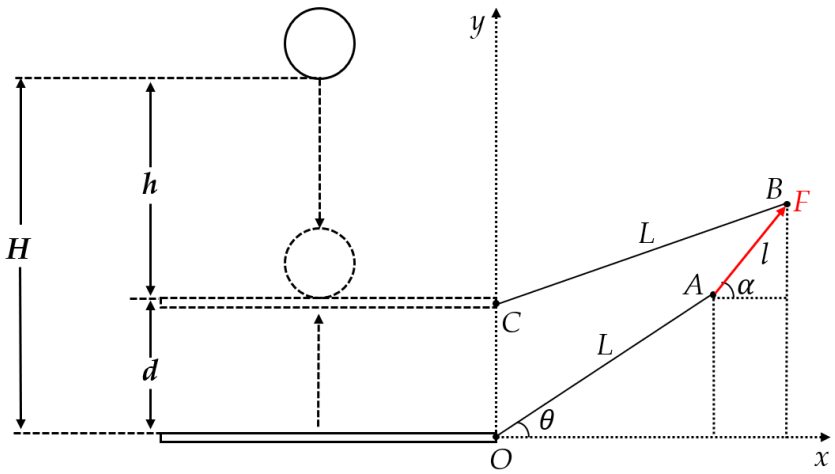

Fig. 2 a schematic diagram of the collision between the drum and the ball

2.2 Dynamic analysis of drum motion

In drum playing, the distance d of drum rise is related to the distance L of the end of the rope from point A to point B, which can be seen from the geometric relationship in FIG. 2.For the convenience of expression, we set up the plane rectangular coordinate system with O as the origin, set up the X-axis in the positive direction to the right side of the bar, and set up the Y-axis in the positive direction to the vertical bar.According to plane analytic geometry,we confirm $O(0,0)$, $C(0,d)$, $B = (L\cos\theta + l\cos\alpha, L\sin\theta + l\sin\alpha)$. Notice that the length L of the rope remained the same during the drum playing Therefore $\overline{CB} = \overline{OA} = L$. According to the Pythagorean theorem

$$(L\cos\theta + l\cos\alpha)^2 + (L\sin\theta + l\sin\alpha - d)^2 = L^2 \tag{5}$$

So we have the relationship between the ascending distance d and the pulling distance L.

When the drum rises to a certain height of d_0, the ball must collide with the drum, and there is a collision between t_0 and d_0

$$\frac{1}{2}gt_0^2 + d_0 = H \tag{6}$$

establish. To fully determine $t_0$and d_0, when the collision occurs, we need to give the dynamic relationship between t and d when the drum is pulled.

Regarding the drum and string as a system, based on the momentum conservation law of the system of particles, we have:

$$nF\cos\alpha\, t - Mgt = Mv - Mv_0 \tag{7}$$

And for the whole system, the energy conservation of the system is as follows:

$$nFl = \frac{1}{2}Mv^2 - \frac{1}{2}Mv_0^2 - Mgd \tag{8}$$

Since the drum is at rest before it begins to move, we assume that $v_0 = 0$. According to formula (7) and (8), we eliminate the variable:

$$2M^2gd + 2MnFl - g^2M^2t^2 + 2MFght^2\cos\alpha = F^2n^2t^2\cos^2\alpha \tag{9}$$

Then by using formula(5)(9),and eliminating the variables l, we can get the equation $\mathcal{F}(t,d) = 0$ about t and d, By combining this equation with formula (6), we can solve.t_0和d_0 at the time of impact The simultaneous formulas (5) and (8) cancel out the variables L, If I plug in d_0 at t_0Can give drum speed size ,v_1 at this time, The speed at which the ball is falling $v_2 = gt_0$.

According to the principle of centripetal-collision, the velocity after collision between drum and ball can be described by formula (3)

$$u_2 = \frac{M(1+e)v_1 - (m - eM)v_2}{M+m} \tag{10}$$

In this way, the maximum height the ball can reach from the drum is

$$h_{\max} = \frac{u_2^2}{2g} \tag{11}$$

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