Lecture T2 –The Pendulum-Based Start Gate (US 8,016,639 B2)

INTRODUCTION

Literally millions of Pinewood Derby races have been run since the inception of the race in 1953, mostly by Cub Scouts and their parents. But the currently available race tracks, without exception, have a serious problem in their car start mechanisms. Refer to the prior art **Figure 1** which points out a typical spring-loaded start mechanism, a version of which is shared by all prior art tracks. As seen in **Figure 1** the spring force is supplied by a strong rubber bands or a spring 26 as shown in some designs such as the original Cub Leader How-To Book design. In other designs the spring force is from a torsional hinge-type spring as in the Derby Magic design. But the spring force supplied therein to move the start posts 22 is about 16 times stronger than necessary. When the start gate bar 23 is released by pulling on the trigger 25 around axis 35 with force such as string 42, there begins a rotation of 23 about hinge axis 24. Then rapidly rotating 23 contacts the bottom of 19, stopping quickly. We will see that this "slap" deceleration occurs over a distance on the order of 30 times shorter than necessary. The above combined effects cause the net deceleration force to be several hundred times more than needed. This "slap", even if damped with a cushion, causes substantial vibration and impact motion of the ramp 19 which jostles the cars, such as 20, thereby interfering with a smooth, fair start. The inherent performance capability of a car and the true winner will thus be masked.

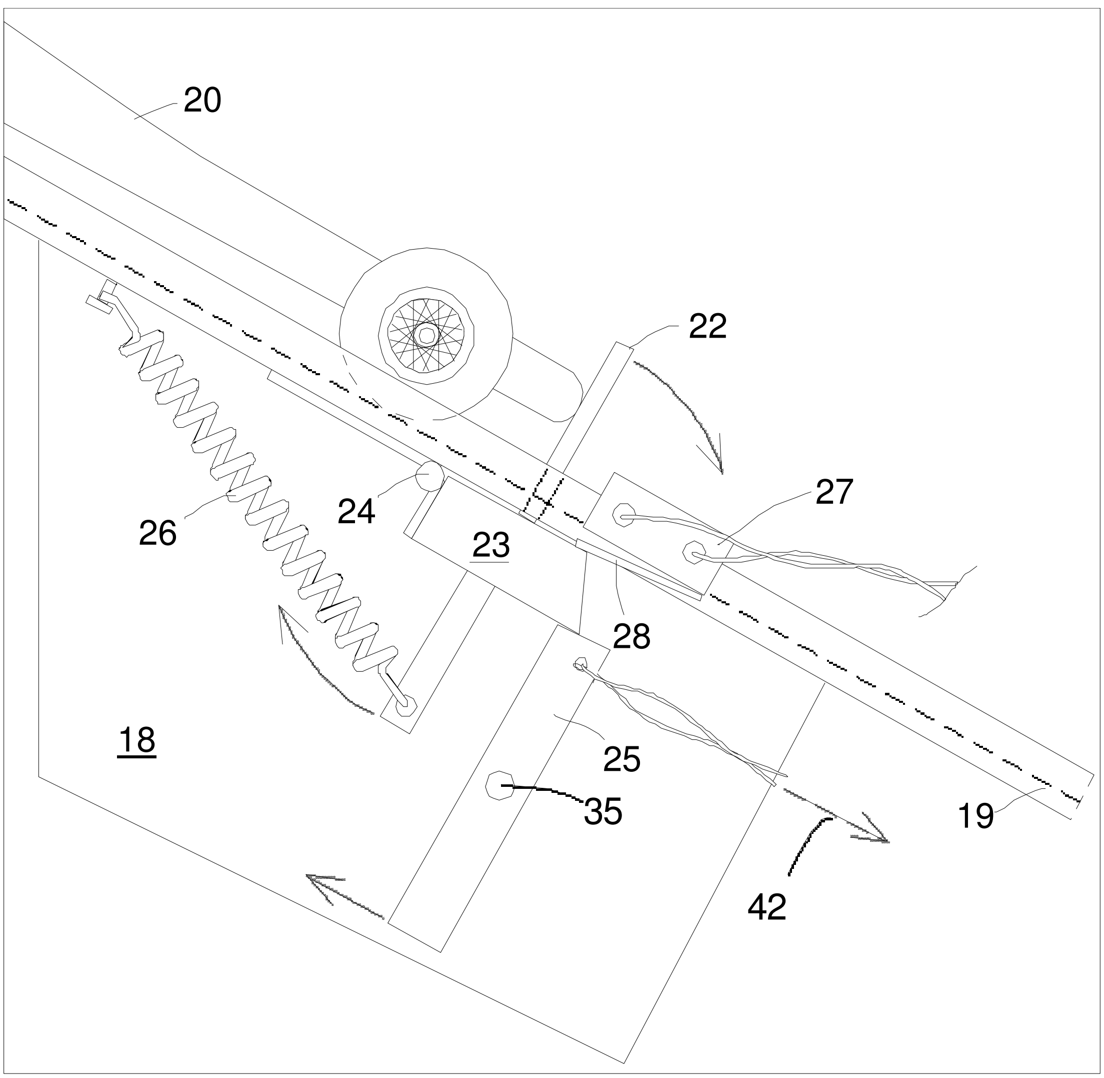

Figure 1 – Prior art view of a typical start gate

THE PENDULUM G-START GATE

This start gate, named the Pendulum G-Start Gate, is shown in side view in **Figure 2**. It is covered by a patent licensed by Hobby Distribution Inc. of Tonawonda, NY. For more detailed physics and drawings, please refer to: http://www.google.co.ve/patents/US8016639 . Also see figures in Lecture T3.

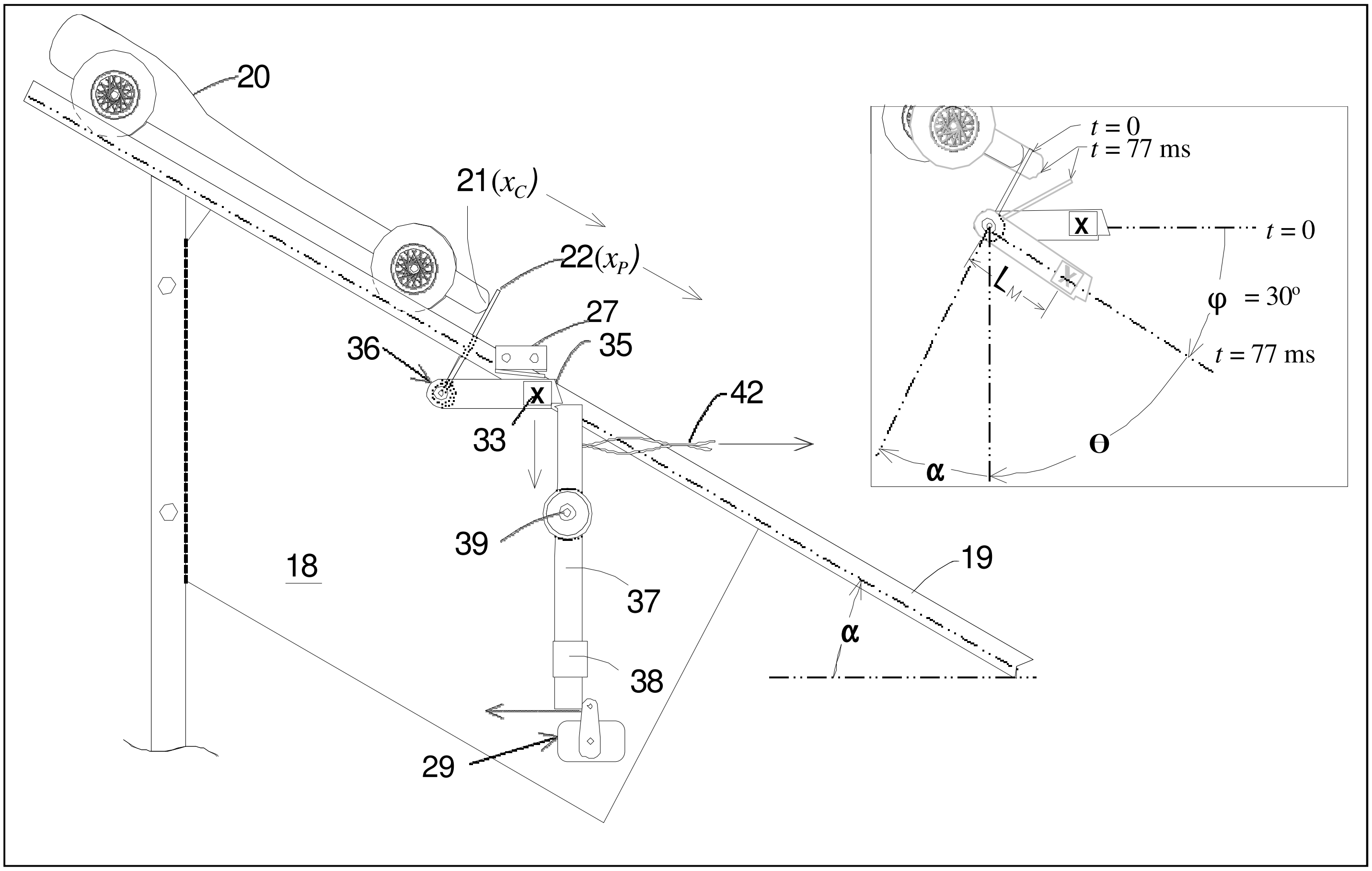

Figure 2 – The Pendulum G-Start Gate

This rigid swingable assembly is comprised of a drop member 35, a cylindrical post support shaft passing through a journal bearing 36, and a plurality of start posts such as 22 equally spaced thereon. The drop member 35 also has a weight attached near the trigger support end. The entire start gate assembly has an effective center of mass (CM), marked by an X shown as 33. The start gate assembly, after being released, swings freely. The start posts such as 22 completely clear the ramp upon swinging, as they initially protrude through the upper end of slots of predetermined length in between guide strips. The pendulum assembly trigger lever 37 is shown in a vertical cocked state, with its lower end weighted by a weight 38. The lever 37 is free to rotate around a journal bearing assembly 39. The trigger lever 37 may be remotely moved by an electromechanical transducer assembly 29 such as a solenoid or other means. The angle of inclination of the track in the vicinity of the top end is α. An end view of the track showing multiple starting posts may be found in the above patent reference. As also shown in **Figure 1**, item 27 is a micro switch for timer start that goes from normally closed to open when the drop member 35 begins its fall. The next Lecture T3 will discuss this time start switch in some detail and also show modified start assembly end views.

AN ANALYSIS OF PENDULUM MOTION

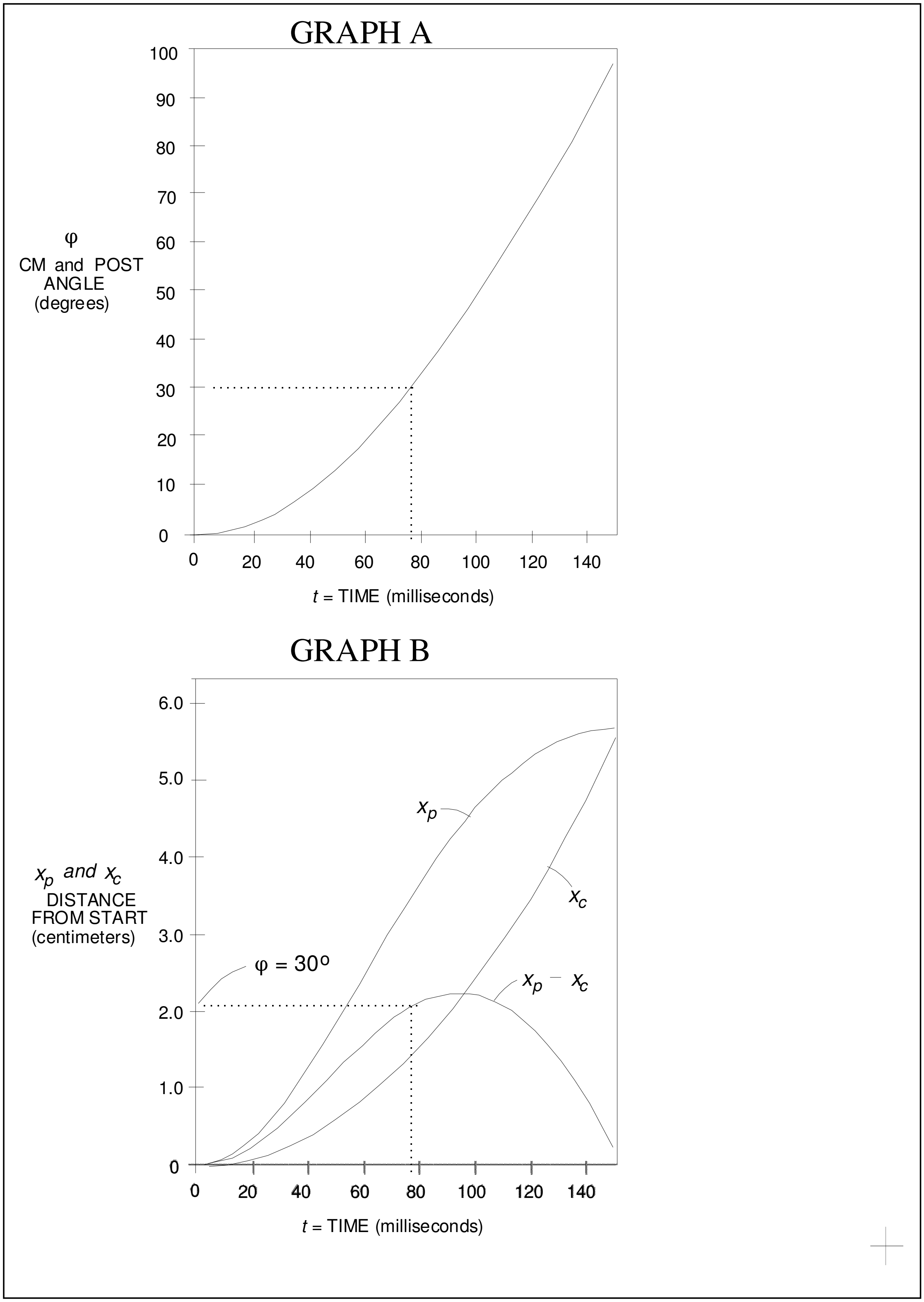

Figure 3 – Analysis of Pendulum Motion

The essence of the invention is first the realization that all cars, being on an inclined ramp, are initially accelerated upon release at substantially less than 1 G, the acceleration due to gravity, whereas a pendulum bob or weight initially falls at precisely 1 G acceleration if it is released at a position horizontal with its fixed pivot point. The second realization is that the starting posts can also be given at least this 1 G acceleration if they are made part of a rigid body which can swing as a compound pendulum and whose effective center of mass is released from a point horizontal with the pendulum's fixed pivot axis.

In **Figure 2**, note that the projection of the start post tip 22 onto the down-ramp direction is measured by x_P. After start, initially this distance x_P must remain larger than the car nose 21 down-ramp distance x_C in order to avoid start post interference with the car. It should be noted that α , which is the angular displacement of the initial start post position from the vertical, is also the angle which the ramp 19 top part makes with the horizontal. In all practical ramps α never exceeds 30° so we will use this value of α below. Because the pendulum assembly is a rigid body, the start post tip 22 and the start assembly including drop member 35 will both rotate according to the same angle. The car acceleration is $G\sin\alpha = 0.5G$ at $\alpha = 30^o$.

Let's first consider what happens in a short period of time right after the drop member is released. The formula for an object moving a distance x from rest under a constant applied acceleration can be derived from Newton's second law as

$$x = ½at^2 \qquad (1)$$

Here a is any constant acceleration and t is the time. If we substitute first 1 G and then 0.5 G for a, we have for the start post and car nose down-ramp movement right after start that:

$$x_{\text{p}} = \frac{1}{2}Gt^2 \qquad (2)$$

$$x_{\text{c}} = \frac{1}{4}Gt^2 \qquad (3)$$

Thus, we have that

$$x_{\text{c}} = \frac{1}{2}x_{\text{p}} \qquad (4)$$

and when the post tip x_{p} has moved , say, 5 thousandths of a centimeter from rest, the car nose x_{c} has moved only 2.5 thousandths of a centimeter. Normally the motion of a pendulum is analyzed relative to the angle θ from the vertical where θ = 0 is the position at rest. The release point angle is the initial condition noted by θ_o. For small swings, where sinθ ~ θ, the simple Physics 101 solution for the time is

$$t = \sqrt{\frac{L_M}{G}}\ cos^{-1}\left(\frac{\theta}{\theta o}\right) \qquad (5)$$

where L_M is the pivot arm length of the pendulum.

By the time the car has rolled down the first meter or so, the start post acceleration and x_P increase rate have become progressively less as the drop member CM falls and the angle φ increases. We must therefore consider the full pendulum motion for a full swing starting initially from $\theta_o = \frac{\pi}{2} = 90^o$. The solution for the time at any starting θ_o is given by a rather complicated function known as an e*lliptic integral of the first kind* , equation (6).

$$t = \frac{\pi}{2}\sqrt{\frac{L_M}{G}}\left[1 + \left(\frac{1}{2}\right)^2 k^2 + \left(\frac{3}{2\cdot 4}\right)^2 k^4 + \left(\frac{3\cdot 5}{2\cdot 4\cdot 6}\right)^2 k^6 + \cdots\right] \qquad (6) \qquad \text{where } k = \sin\left(\frac{\theta_o}{2}\right)$$

So for $\theta_o = 90^o$, $\sin(45^o) = \frac{1}{2}\sqrt{2}$, and $k = 0.707$. The correct time from (6) is about 34% slower than from the simple small θ approximation of (5).

The insert in **Figure 2** shows the start post assembly in grey outline as it drops down through angle $\varphi = 30^o$ from the horizontal . We then use φ as the complement for various θ_o in Eq (6) and plot the results we get **Figure 3A** which shows how φ depends on the time t. For example, **Figure 3A** (and **Figure 2** insert) shows that when φ = 30 ^{o}, the time is 77 milliseconds (ms) after start.

The down-track projection distance of the start post tip is

$$x_p = L_p \sin\varphi \qquad (7)$$

Then, choosing typical distances L_P = 5.72 cm (2.25 in) and L_M = 5.08 cm (2.00 in), in **Figure 3B** we plot the start post tip distance x_P down-track from Eq (7) using φ for increasing t. Also plotted is the simple quadratic function in Eq (3) giving the car nose position x_C. The separation distance between the start post tip and the car nose is $x_P - x_C$. At the $\varphi = 30^o$ rotation angle, occurring at 77 ms from start as seen in **Figure 3B**, the tip becomes lower than the car body bottom and from then on it is clear there is no possibility of post interference with the car. Fig 3B shows that when this occurs at 77 milliseconds (ms) from start the post tip is already about 2 cm ahead of the car nose. The separation continues to increase to a maximum at about 95 ms at which point the angle φ is almost 45^o and the start post tip is passing beneath the ramp top surface, still about 2 cm ahead of the car front. For larger angles φ the distance x_P is the post projection onto the bottom of the track.

The pendulum assembly continues to swing down and to the left as the car passes overhead. If a slow car has so much friction that the start post on its back swing (at about t=500 ms) could interfere with the car bottom, then the car would not have reached the finish line even without such interference. Thus it is proven that a pendulum start post cannot interfere with a car, even with a rather steep ramp angle of 30°. Some ramps may have an incline angle α as low as 20°. The initial acceleration of a car is then only 0.34 G. There would thus be even more distance between the car nose and the falling start post compared to the 0.50 G case just considered where α=30°. When installing the pendulum assembly on a new specific ramp, the set screw in assembly 36 is tightened with the drop member 33 horizontal and with the start posts 22 positioned perpendicular to the ramp surface. This gives a proper angle between the start posts and drop member. The pendulum assembly, especially the journal bearings, can be factory installed on mounting plates 18 and 45 for quick retrofit installation on any of the popular ramps in the field.

As a final point of theory, we can compare the gate slap deceleration force of a prior art spring-loaded pendulum assembly with the present embodiment. Prior art springs use a cocking force of about 454 g (one pound, or 16 oz). On the average, ½ of this force, or 227 g (8 oz), travels about 5.08 cm (2 inches) as the spring is stretched. This leads to an energy of force times distance equal to 1153 g-cm (16 oz-in). This energy content must be dissipated by mashing, say, a 0.635 cm (¼ inch) diameter rubber tubing used as a cushion between the rotating start gate hinge 24 or post support bar 23 and the ramp bottom. The deceleration force is then the energy content divided by the impact distance giving 1816 g (64 oz). On the other hand, the pendulum starting energy content is simply the 14.2 g weight (½ oz) raised to a height of

5.08 cm (2 inches) or 72.1 g-cm (1 oz-in). The pendulum will swing back and forth about 3 or 4 times with the CM traveling a total distance on the order of 15.2 cm (6 inches) before coming to rest. The net average deceleration force, which is dissipated as friction in the journal bearings 36 and 51, is only 4.73 g (0.17 oz). The prior art deceleration force is thus about 384 times more than in the current embodiment. Notice all masses above are actually their weight, i.e., force, equivalents.

There follows a slow motion video (**Initial Car-Post Motion**) of two cars being released showing that the starting posts travel about twice as fast as the car front and reappear on the back swing only after the cars are already several car lengths down the ramp. The swinging drop member 35 is shown in (**Pendulum Swing Motion**). The purpose of the red wire will be explained in the next Lecture T3.