Pin – to – PAP of a Bowling Ball

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Abstract

Inertia tensors are used to specifically find the rotation around any axis of a rigid body. This is useful because the axis with which the body rotates may change with time. Additionally, inertia tensors are used to find principle axes, which are the axis where the angular momentum is in the same direction as the axis of rotation.

For bowlers, the ideal path of a bowling ball is for the ball to flare increasing the chances for all the pins to fall down. In order to do this, the bowler has to spin the ball. If the ball is spun correctly, the positive axis point will have a precession. As the axis precesses down the lane, the ball will begin the curve.

One way to do this is by adding a weight block in the inner core. This will offset the PAP. In my program, I am going to be solving for the principle axis of different positions of the weight block.

Background

Bowling balls are typically made with different layers. The base layer is a solid core. This is usually made with a dense metal. These cores can either be symmetrical or asymmetrical. Attached to the core is a weight block, which is made of a even denser metal. Surrounding The core and weight block is an inner shell typically made of a polymer. This is surrounded by an outer shell, which is typically made out of a urethane.

I have decided to model an asymmetric core. The spherical core is made out of graphite with a mass density of 2.266 g/cm^3. Adjacent to this is a cubic shaped weight block made out of steel with a mass density of 7.8 g/cm^3. This block and shell is surrounded by a thin shell. This shell is made out of polyethylene terephthalate with a mass density of 1.38 g/cm^3. Finally, the outer core is made of a polyurethane shell with a mass density of 1.002 g/cm^3. In order to find the total inertia tensor for the bowling ball, I will have to sum the inertia tensors for each component. To find the inertia tensor of the steel block, I used Simpson's three dimensional integration technique. The other three components of the bowling ball assume radial symmetry, so I was able to find these numerically. With this, I used a rootfinder to obtain the zeros of the eigenvalue in order to find the principal axis.

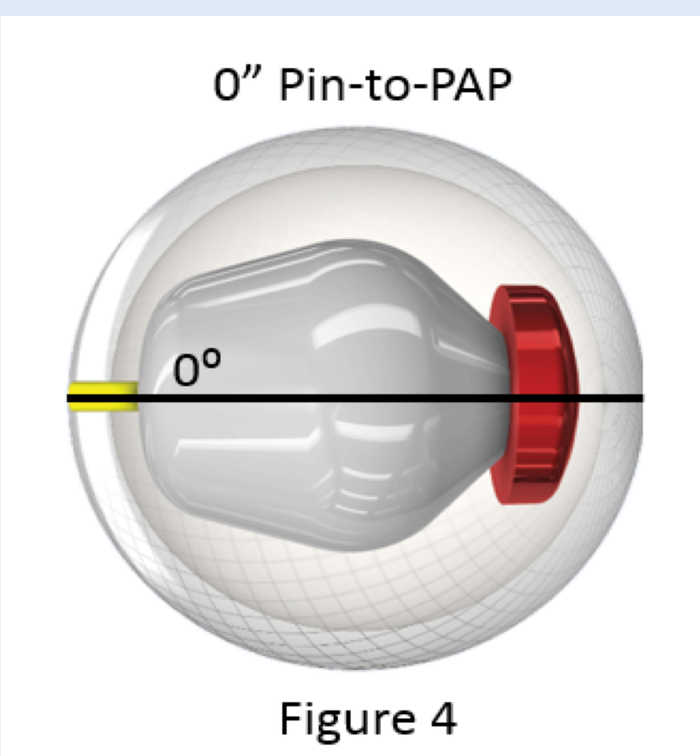


Figure 4

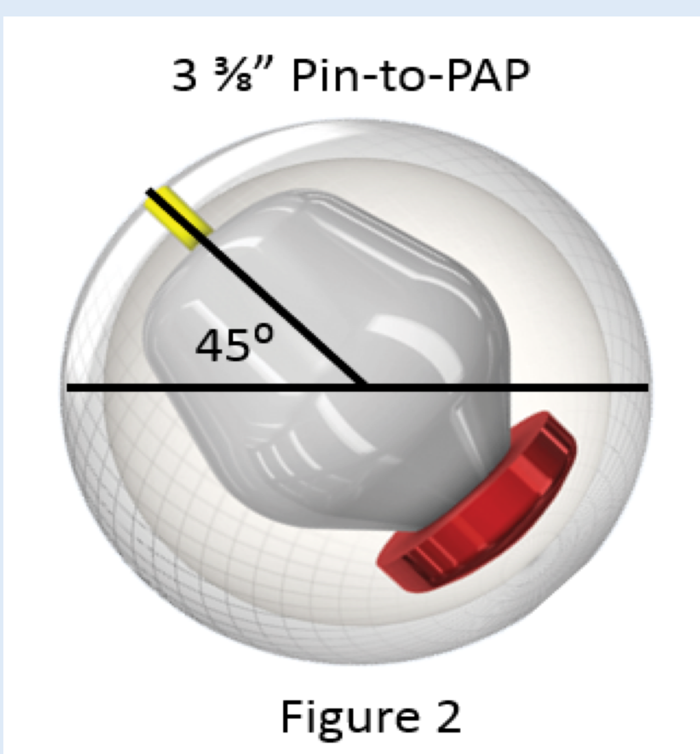
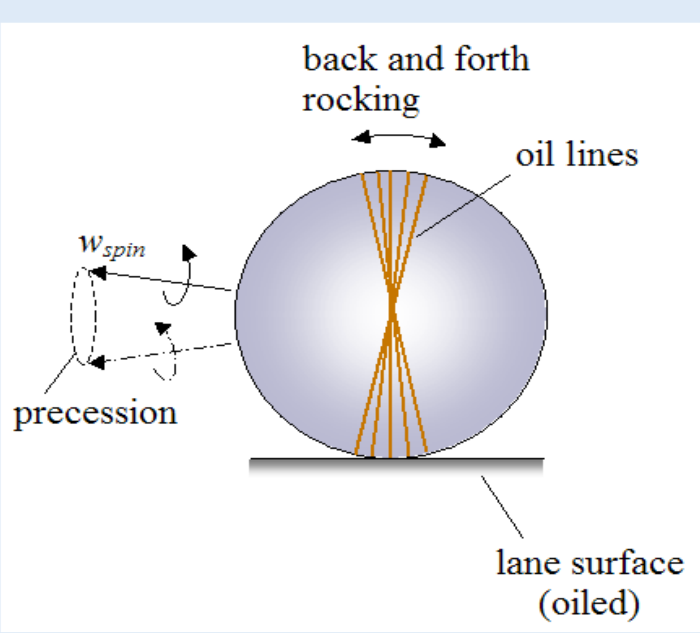
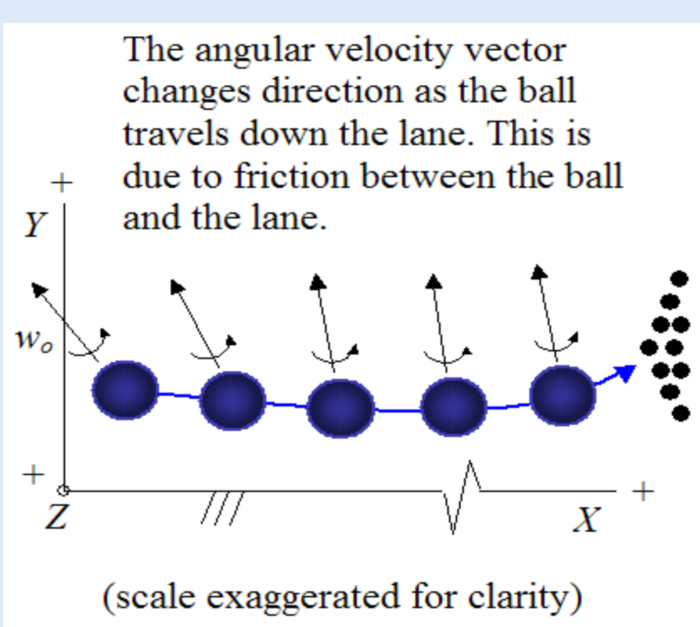


Figure 2

Above is a visual representation of the core. The mass block is offset from the Horizontal axis. In my model, the weight block is flipped and the pin starts pointing to the right (y-axis)





As the angular momentum of the bowling ball changes, it will start to precess (left image). As the ball has a greater precession, it will have more friction with the lane which will cause the ball to flare (right image).

References

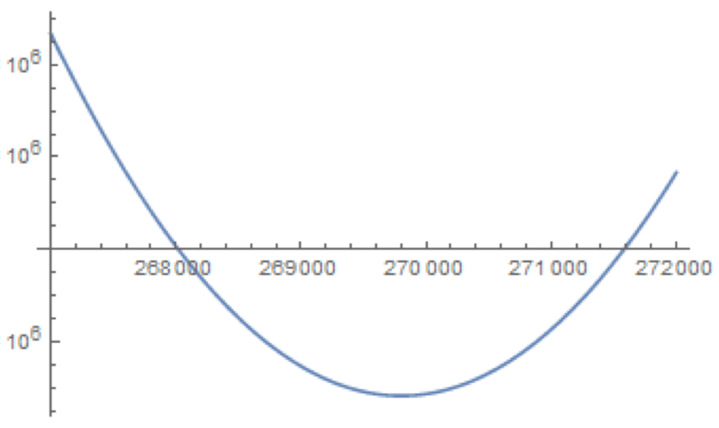
- Physics of bowling: *What Makes Bowling Balls Hook?*, Cliff Frohlich, American Association of Physics Teachers, 2004)
- "Bowling Ball." *Wikipedia*, Wikimedia Foundation, 2 Dec. 2018, en.wikipedia.org/wiki/Bowlingball
-https://www.real-world-physics-problems.com/images/xphysics_bowling_7.png.pagespeed.ic.TSktm0Eans.png
-http://news.stormbowling.com/wp-content/uploads/2017/05/Figure-2-2.png
-http://news.stormbowling.com/wp-content/uploads/2017/05/Figure-4-1.png

Data

```
dX11[f11_, a_, b_, Ns_] := Module[{Ia, j, dx, Y, N},
  N = Ns / 2;
  Y = Mod[N, 1];
  If[Y == 0,
   dx = (b - a) / Ns;
   Ia = 0.0;
   For[j = 0, j ≤ Ns - 2, j = j + 2,
    Ia = Ia + (1 / 3) dx (f11[a + j dx] + 4 f11[a + (j + 1) dx] + f11[a + (j + 2) dx]);
   ];
   Return[Ia];
   , Print["please input and even number of steps"]]
 ]
```

Figure 1.

```
Rationalize[RootFinder[F, 268000, .0001], .001]
Rationalize[RootFinder[F, 271500, .0001], .001]
```




```
The bracket is:{268020., 268020.}
The number of iterations is: 394894
11524849
--------
   43
```

Figure 2.

```
EE = MatrixForm[( 267362.47909 - λ1          0                 0
                       0            271545.1749 - λ1     356.717
                       0                356.717      268055.839 - λ1 )]
λ1 = 271581.269
```

Figure 3.

Angle	Ixx	Ixy	Ixz	Iyx	Iyy	Iyz	Izx	Izy	Izz
0 Degrees	266649.043	0	0	0	272187.1749	0	0	0	266700.4038
30 Degree	267419.4438	0	0	0	271866.1749	385.2	0	385.2	267791.8038
37.5 Degree	267416.9967	0	0	0	271711.3367	383.9764	0	383.9764	267944.1949
45 Degree	267362.479	0	0	0	271545.1749	356.7176	0	356.7176	268055.839
52.5 Degree	267273.7847	0	0	0	271379.0131	312.3704	0	321.3704	268133.3065
60 Degree	267169.3924	0	0	0	271224.1749	260.1742	0	260.1742	268183.7524
90 Degree	266905.8438	0	0	0	270903.1749	128.4	0	128.4	268241.2038

Table 1.

Angle	ωy from ƛ2	ωz from ƛ2	ωz from ƛ2	ωz from ƛ3
0 Degrees	0.000ωz	0ωy	0.000ωz	0.000ωy
30 Degree	-0.093ωz	-10.671ωy	0.093ωz	10.671ωy
37.5 Degree	-0.100ωz	-9.911ωy	0.100ωz	9.911ωy
45 Degree	-0.101ωz	-9.882ωy	0.101ωz	9.882ωy
52.5 Degree	-0.095ωz	-10.485ωy	0.095ωz	10.485ωy
60 Degree	-0.084ωz	-11.771ωy	0.084ωz	11.771ωy
90 Degree	-0.048ωz	-20.779ωy	0.048ωz	20.779ωy

Table 2.

Results and Conclusion

The first three figures are little snippets of the module used to find the inertia tensors and the eigenvalues. The first figure is an integration over the x axis for the Ixx term. The second figure shows the root finder of the determinant . The third figure shows the tensor subtracted by an eigenvalue. These results in tables 1 and 3 came out the way I expected them to. It would make sense for one of the principal axis to point through the z axis, while the other two would be opposites of each other. Since the weight block is shifted between the z and y axis, there should not be any dependence in the x axis. I didn't include this first principal axis since for each case, the angular velocity in the y and z direction are zero which indicates the direction is through the x-axis.

Rather than putting the angular velocities as a unit vector, I left it in the omega form to keep the data looking cleaner. This indicates that the off axis approaches 45 degrees from either direction, the difference between the y and z angular velocities gets smaller.

When serious bowlers try to find the right pin-to-PAP distance for their balls, they will use a test ball to see the natural spin off their release. For a future project, it would be interesting to see the rate of precession with the different off axis angles. The module is a good start, but it would require a torque. This could possibly be modeled by the "test" ball. If able to find the torque, then the angular frequency can be found. Then this relationship could be modeled.

If I were to do this project again , I would make a more intricate core to the bowling ball. This would include x axis dependence which would give all six products of inertia. I initially tried doing this, but found that the root method was not precise enough. Part of the reason is that the root finder takes many iterations as seen in figure two for only the one thousandths place.