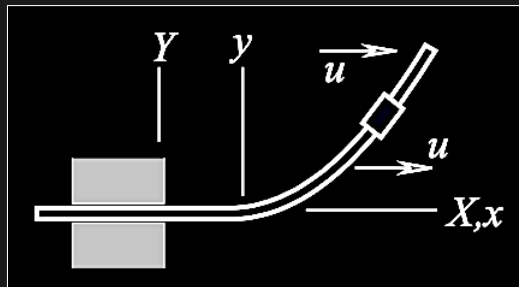


October 14, 2024

MODULE 7 — Assignment

EXERCISE 7.1

The slider descends along a curved guide as the guide translates to the right at the constant speed u . The shape of the guide bar in terms of a body-fixed set of coordinates is $y = \beta x^2$. Generalized coordinates selected for this system are the fixed X and Y coordinates of the collar. Independently derive the velocity and configuration constraint equations relating X and Y . Then show that integration of the velocity constraint yields the configuration constraint.



Given the graphic provided, we can write that the velocities in the generalized coordinates are:

$$\begin{aligned}\dot{X} &= \dot{x} + u \\ \dot{Y} &= \dot{y} = 2\beta x\dot{x}\end{aligned}$$

Taking the integral of \dot{X} :

$$X = ut + x \quad \rightarrow \quad x = X - ut$$

We can combine the above, and find that the velocity constraint is:

$$\dot{Y} = 2\beta (X - ut) (\dot{X} - u)$$

Or:

$$2\beta (X - ut) \dot{X} - \dot{Y} - 2\beta (X - ut) u = 0$$

→ Answer

The configuration constraint is:

$$Y = y = \beta x^2 = \beta (X - ut)^2$$

More simply:

$$Y = \beta (X - ut)^2$$

→ Answer

Looking at the velocity constraint above, we know by reversing the chain rule for derivatives:

$$\int f(g(x)) g'(x) dx = F(g(x)) + C$$

Where for the velocity constraint:

$$f(g(x)) = 2(X - ut), \quad F(g(x)) = (X - ut)^2$$

Therefore:

$$Y = \beta \int (2(X - ut)) (\dot{X} - u) dt = \beta \int g(t) g'(t) dx = \beta (X - ut)^2 + C$$

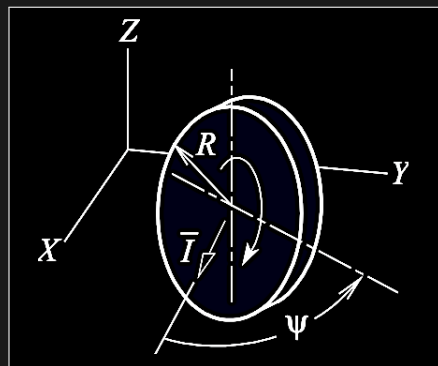
More simply:

$$Y = \beta (X - ut)^2 + C$$

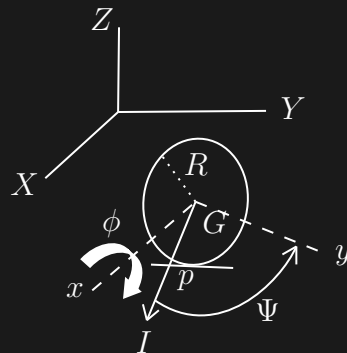
→ Answer

EXERCISE 7.12

The figure shows a disk that is constrained to roll without slipping on a horizontal XY plane, such that its plane remains vertical. Let the position coordinates X and Y of the geometric center, the heading angle Ψ , and the spin angle ϕ be generalized coordinates. Describe the velocity constraints between these generalized coordinates. From those results, determine the number of degrees of freedom, and whether the system is holonomic.



This system can be defined by the following sketch:



Constructing the angular velocity vector $\bar{\omega}$ of xyz by vectorially adding the simple rotation rates according to:

$$\bar{\omega} = \omega_1 \bar{e}_1 + \omega_2 \bar{e}_2$$

This gives us:

$$\bar{\omega} = \dot{\phi} (-\bar{i}) + \Psi \bar{k} = -\dot{\phi} \bar{i} + \Psi \bar{k}$$

The velocity of the center of the disk at point G from the no-slip point, point p is defined as:

$$\bar{v}_G = \bar{v}_p^0 + \bar{\omega} \times \bar{r}_{G/p}$$

This evaluates to:

$$\bar{v}_G = \bar{\omega} \times \bar{r}_{G/p} = (-\dot{\phi} \bar{i} + \Psi \bar{k}) \times R \bar{k} = R \dot{\phi} \bar{j}$$

The rotation from the body frame to the inertial frame de defined by the following sequence of rotations:

$$R_{\text{rot}} = \begin{bmatrix} \cos(-\frac{\pi}{2}) & -\sin(-\frac{\pi}{2}) & 0 \\ \sin(-\frac{\pi}{2}) & \cos(-\frac{\pi}{2}) & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \cos(\Psi) & -\sin(\Psi) & 0 \\ \sin(\Psi) & \cos(\Psi) & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

Or:

$$R_{\text{rot}} = \begin{bmatrix} \sin(\Psi) & \cos(\Psi) & 0 \\ -\cos(\Psi) & \sin(\Psi) & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

Therefore, the velocity \bar{v}_G can be expressed as:

$$\bar{v}_G = R_{\text{rot}} (\bar{v}_G)^{xyz} = \begin{bmatrix} \sin(\Psi) & \cos(\Psi) & 0 \\ -\cos(\Psi) & \sin(\Psi) & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 0 \bar{i} \\ R \dot{\phi} \bar{j} \\ 0 \bar{k} \end{bmatrix} = \begin{bmatrix} R \dot{\phi} \cos(\Psi) \bar{I} \\ R \dot{\phi} \sin(\Psi) \bar{J} \\ 0 \bar{K} \end{bmatrix}$$

This can be expressed as the following velocity constraints:

$$\dot{X} = R \dot{\phi} \cos(\Psi)$$

$$\dot{Y} = R \dot{\phi} \sin(\Psi)$$

→ Answer

Or:

$$\begin{aligned}\dot{X} - R \dot{\phi} \cos(\Psi) &= 0 \\ \dot{Y} - R \dot{\phi} \sin(\Psi) &= 0\end{aligned}$$

This system has **4** generalized coordinates, $\mathbf{q}_i = \{\mathbf{X}, \mathbf{Y}, \mathbf{\Psi}, \mathbf{\phi}\}$, and **2** velocity constraints. Subtracting the two gives us **2 degrees of freedom**.

→ Answer

Evaluating whether the system is holonomic:

$$\begin{aligned}a_{11} &= 1, \quad a_{12} = 0, \quad a_{13} = 0, \quad a_{14} = -R \cos(\Psi), \quad b_1 = 0 \\ a_{21} &= 0, \quad a_{22} = 1, \quad a_{23} = 0, \quad a_{24} = -R \sin(\Psi), \quad b_2 = 0\end{aligned}$$

Looking at the terms a_{13} and a_{24} :

$$\begin{aligned}\frac{\partial f_1}{\partial \Psi} &= g_1(X, Y, \Psi, \phi) \cdot 0 \\ \frac{\partial f_1}{\partial \phi} &= g_1(X, Y, \Psi, \phi) \left(-R \cos(\Psi) \dot{\phi} \right)\end{aligned}$$

The first equation implies that the function f_1 must be a function of Ψ , however the second implies that the derivative of the function with respect to Ψ will be zero. This is inconsistent. There is no integrating factor g_1 that can satisfy both of these, therefore the system is not integrable.

Since the velocity constraints are not integrable, the system is **non-holonomic**.

→ Answer

Submitted by Austin Barrilleaux on October 14, 2024.