

The Roberval Balance

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Abstract

The Roberval Balance, invented in 1669 by French mathematician Gilles de Roberval, is a unique balance that has perplexed many upon first encountering the mechanism. This mechanism is a parallelogram that when its arms comprise a perfect parallelogram and the moveable weights or poises are of equal weight, a condition of equilibrium will be maintained regardless of the position of each weight from the arm on which it is suspended. The COMSOL Multiphysics® software is used to validate the static stress assumptions by analyzing the mechanism under a multi-body dynamics physics environment. The results of numerous FEM formulations give credence to the hypothesis presented within this study and validate the engineering analysis that explains the mysterious nature of this mechanism.

The Roberval Balance is based on parallelograms to maintain equilibrium regardless of orientation and weight distribution. Compared to a common lever balance, when two objects of equal mass are placed on two opposing arms, the system remains in equilibrium regardless of the position of the object on its respective arm. The balance does not center itself and remains balanced in equilibrium irrespective of its configuration. The question is why this occurs.

The mechanism itself is built off a generic parallelogram structure, introducing a degree of symmetry to the reaction forces within the system. The device was discretized using 14,530 nodes. Additionally, the weighing platforms themselves are built as a cantilever type structure that hangs off the sides of the parallelogram mechanism. A cantilever support, in planar motion, retains all three reaction-force components, and fully constrains the point of attachment, which is an important feature.

A load applied onto the weighing platform can then be decomposed into a force and couple moment acting at the cantilever connection. This is where the mystery in the mechanism is resolved. With the three reaction-force components supplied by a cantilever connection, the couple moment that is generated by placing an object at distance is fully resolved with the internal reaction moment, and thus leaves the vertical load of the object resulting from gravitational acceleration. When two objects of equal mass are placed on the weighing platforms, the couple moments are eliminated and the two equal vertical forces act along the sides of the mechanism. With the mechanism structure being a parallelogram, these two loads will always be vertical, and thus no variation occurs as the mechanism is moved from the horizontal configuration. This ultimately leaves the system in a state of equilibrium, regardless of the included couple moment or configuration,

which resolves the mystery. Multiple FEM simulations were formulated using the COMSOL® software, utilizing both multi-body dynamics and static stress physics environments, to verify these assumptions.

Figures used in the abstract



Figure 1: The Roberval Balance