Governors and Feedback Control

Cybernetics

Maxwell's 1868 paper "On Governors", on speed regulation mechanisms using feedback, was largely overlooked before 1948 when Norbert Wiener (1894-1964) designated the emerging field of control and communication as Cybernetics, derived from the Greek *χυβερνήτης* or steersman.

Feedback control

Cruise control regulates a vehicles speed by comparing the difference between the current speed and the desired speed to derive an error. Feedback control then adjusts the current speed to the desired speed, minimising the error. Governors (a latin corruption of *χυβερνήτης*), the cruise control systems of Maxwell's time, were pioneered by James Watt (1736-1819), who controlled the steam inflow (to a valve) by means of a flying ball. Maxwell's colleague on the electrical standards committee, Fleeming Jenkin (1833-1885), further refined governor designs leading Maxwell to mathematically model these speed controllers.

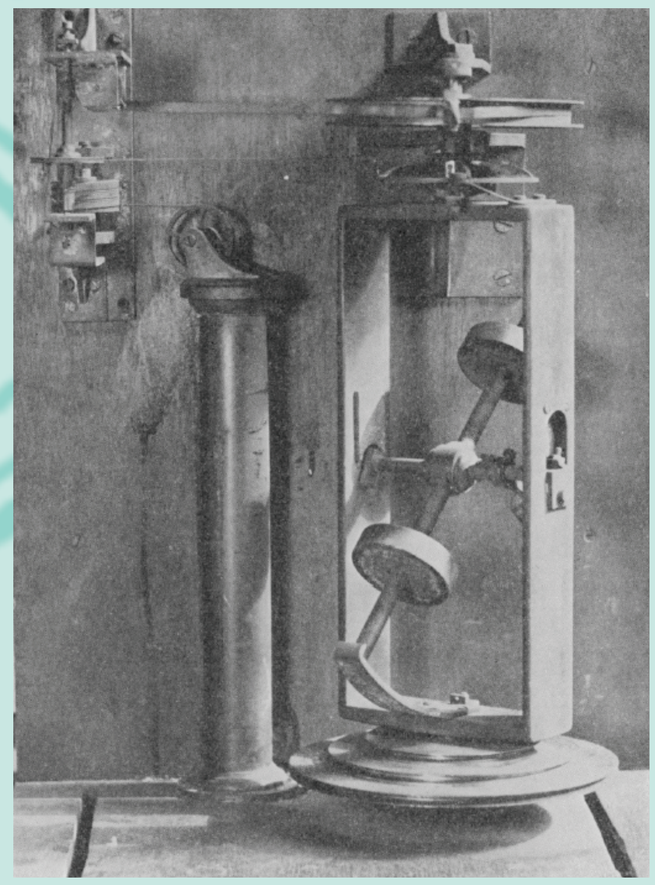
Stability analysis

Maxwell's 1868 paper highlighted the fundamental distinction between moderators and governors. In *moderators*, the correcting torque is proportional to the speed error, whereas *governors*, also contain a term *proportional* to the *integral* of the error. Thus Watt's flying ball controller is strictly a moderator while the later designs do include integral action. Maxwell observed that, to achieve exact speed regulation with zero steady-state error, feedback control must minimise the 'integral of the speed error'.

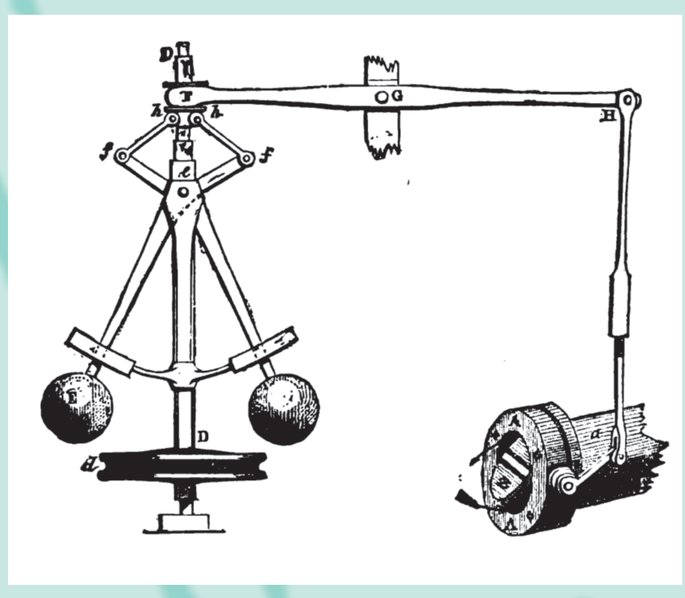
Maxwell placed stability at the core of his analysis of feedback mechanisms. By assuming the parameter errors were small, he *linearised* the equations of motion for the errors and reduced 'stability analysis' to the algebraic determination of whether all the roots of a certain polynomial have negative real parts, as used in his investigations on Saturn's rings. Edward Routh (1831-1907), his Cambridge colleague, later provided a more general solution which won the 1877 Adams Prize (when Maxwell served as examiner). The Routh-Hurwitz stability criterion is taught today with linearisation being the first step in modern control theory design.

Maxwell's heritage

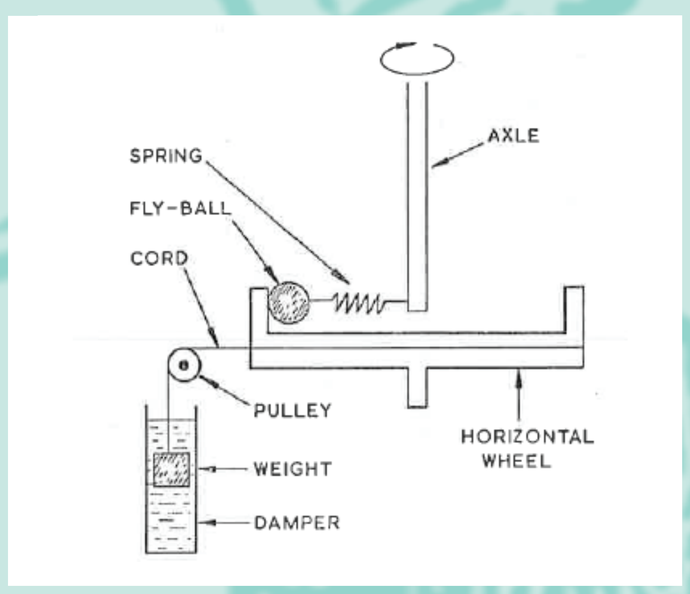
Wiener acknowledged that it took one of greatest minds to foresee the importance of the mathematical science of feedback, when he designated Maxwell as the father of modern automatic control, which still remains one of today's most significant concepts in contemporary science and engineering.



Fleeming Jenkin's governor, as used with Maxwell when determining the measurement of the ohm, courtesy of *Whipple Science Museum, University of Cambridge*.



James Watt's centrifugal speed controller (Wikipedia).



Principle of Fleeming Jenkin's flying ball governor, courtesy *Transactions of ASME: Journal of Dynamical Systems, Measurement and Control, 1976.*

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