自动控制的基本概念

Outline

Contents

1 自动控制历史

1.1 自动控制装置

Centrifugal governor

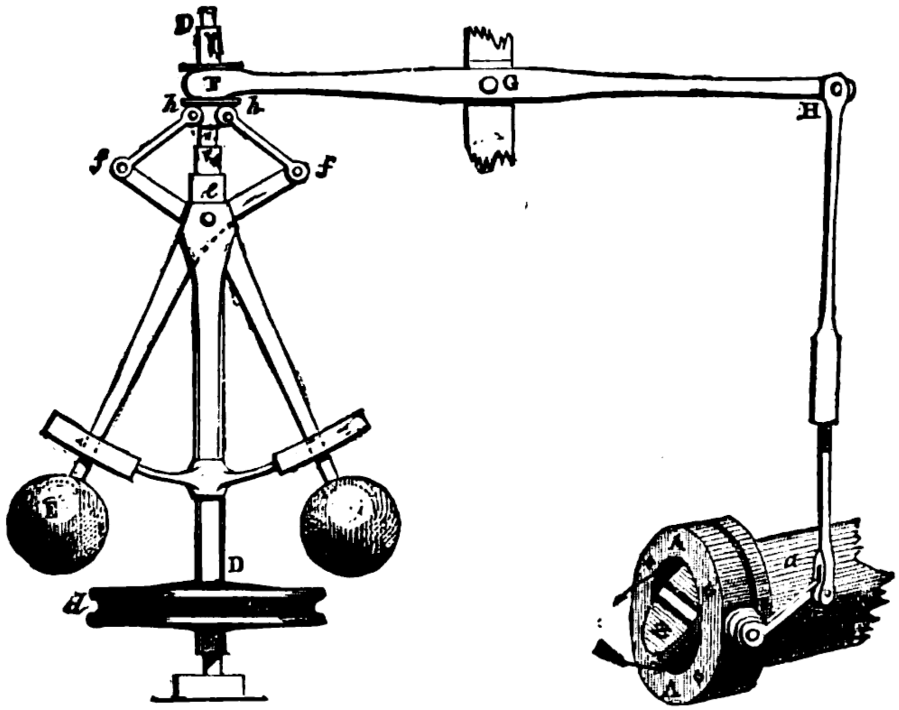
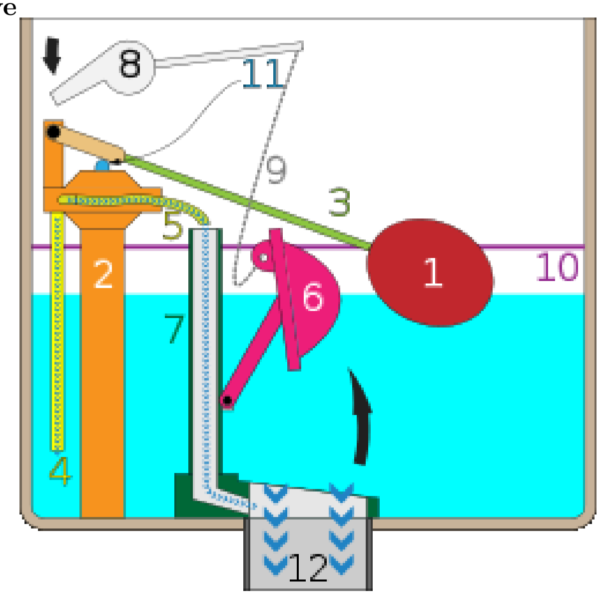


FIG. 4.—*Governor and Throttle-Valve.*

Tolilet Valve

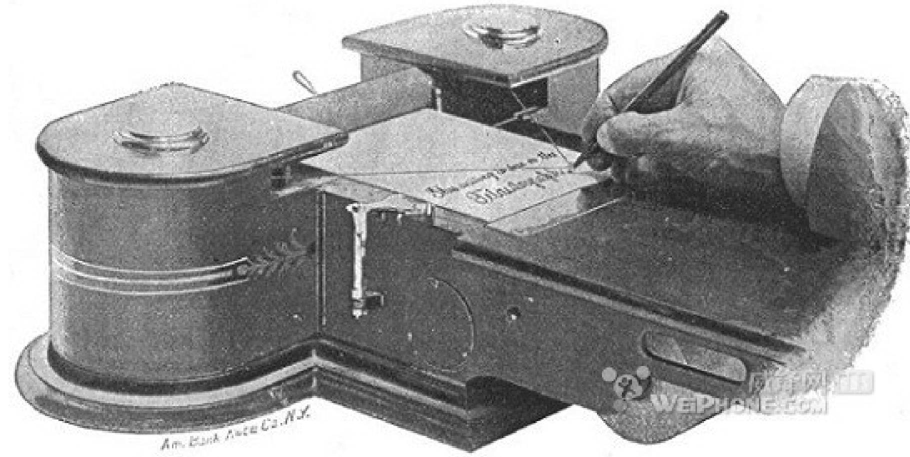


指南车

莲花漏

Windmil fantail

telautograph



1.2 控制理论的发展

Pierre-Simon Laplace

- Laplace 
- Introduction Pierre-Simon Laplace (1749-1827) invented the Z-transform in his work on probability theory, now used to solve discrete-time control theory problems. The Z-transform is a discrete-time equivalent of the Laplace transform which is named after him.

Joseph Fourier

- Fourier 

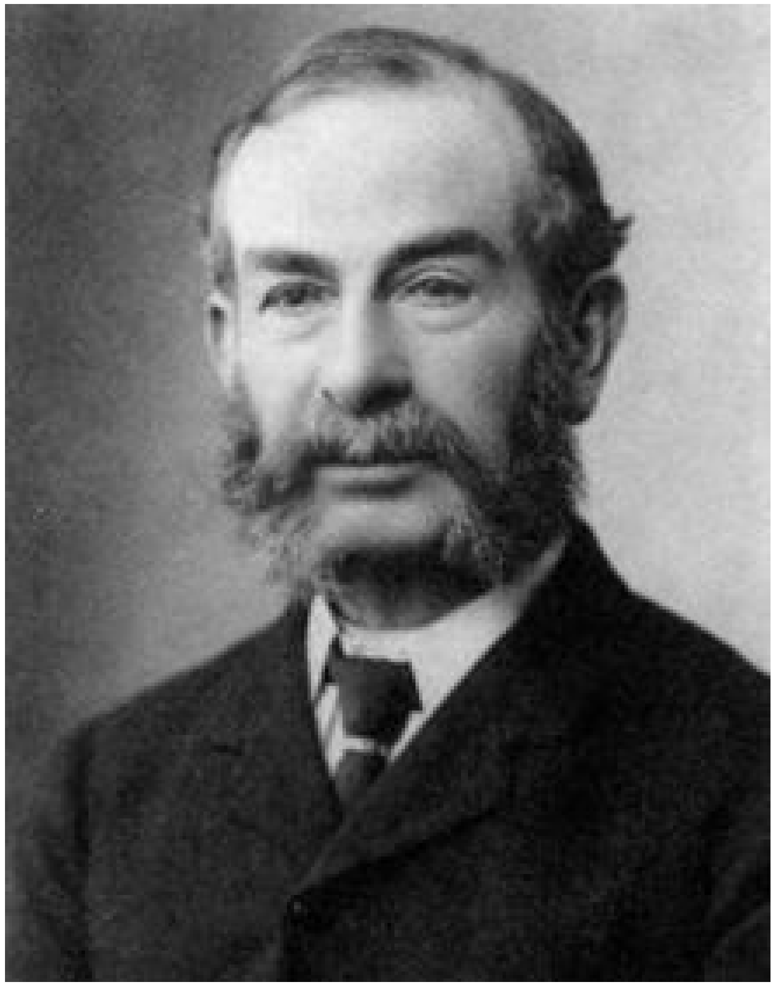
- Introduction Joseph Fourier (21 March 1768 – 16 May 1830) was a French mathematician and physicist born in Auxerre and best known for initiating the investigation of Fourier series and their applications to problems of heat transfer and vibrations. The Fourier transform and Fourier's Law are also named in his honour. Fourier is also generally credited with the discovery of the greenhouse effect.

James Clerk Maxwell

- Maxwell 

- Introduction James Clerk Maxwell (FRS,Fellow of the Royal Society of London. FRSE,Fellow of the Royal Society of Edinburgh) (13 June 1831 – 5 November 1879) published a paper On governors in the Proceedings of Royal Society, vol. 16 (1867–1868). This paper is considered a central paper of the early days of control theory. Here “governors” refers to the governor or the centrifugal governor used to regulate steam engines.

Edward John Routh

- Routh 

- Introduction Edward John Routh (FRS,Fellow of the Royal Society of London) (20 January 1831 – 7 June 1907), was an English mathematician, noted as the outstanding coach of students preparing for the Mathematical Tripos examination of the University of Cambridge in its heyday in the middle of the nineteenth century. He also did much to systematise the mathematical theory of mechanics and created several ideas critical to the development of modern control systems theory.

Adolf Hurwitz

- Hurwitz 
- Introduction Adolf Hurwitz (26 March 1859 – 18 November 1919) was a German mathematician who worked on algebra, analysis, geometry and number theory. In the field of control systems and dynamic systems theory he derived the Routh–Hurwitz stability criterion for determining whether a linear system is stable in 1895, independently of Edward John Routh who had derived it earlier by a different method.

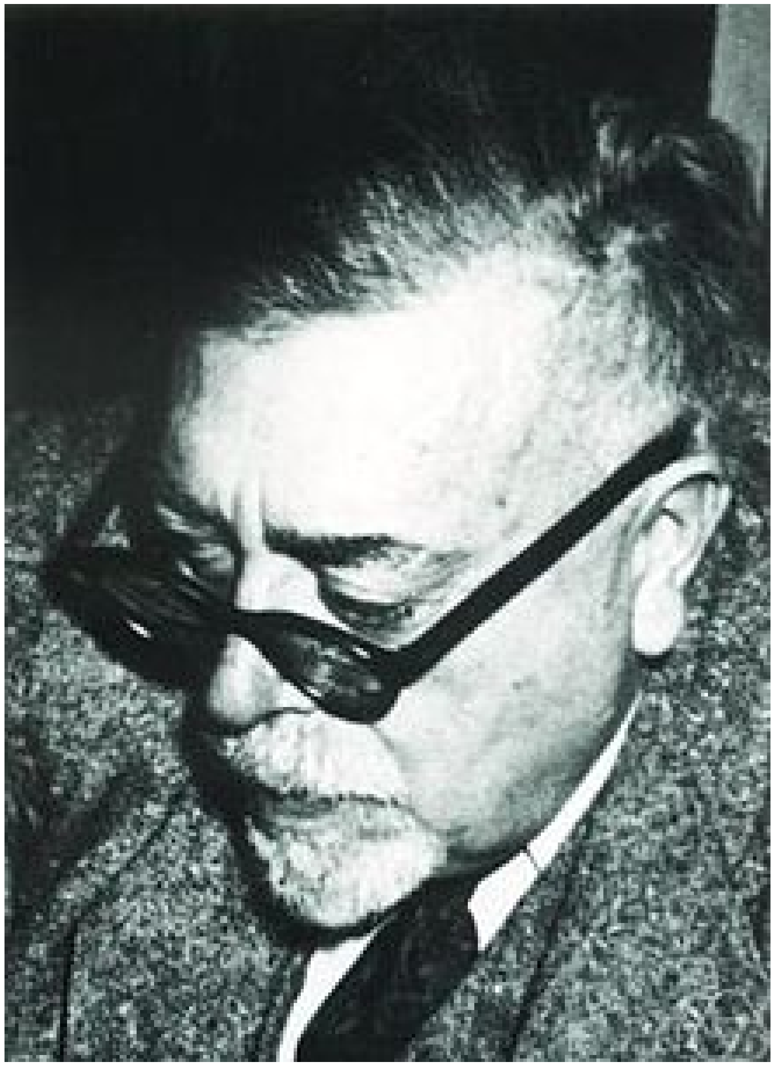
Alexander Lyapunov

- Lyapunov 
- Introduction Alexander Lyapunov (1857–1918) in the 1890s marks the beginning of stability theory.

Harry Nyquist

- Nyquist 
- Introduction Harry Nyquist (1889–1976), developed the Nyquist stability criterion for feedback systems in the 1930s.

Norbert Wiener

- Wiener 

- Introduction Norbert Wiener (1894–1964) co-developed the Wiener–Kolmogorov filter and coined the term cybernetics in the 1940s.

Harold S. Black

- Black 

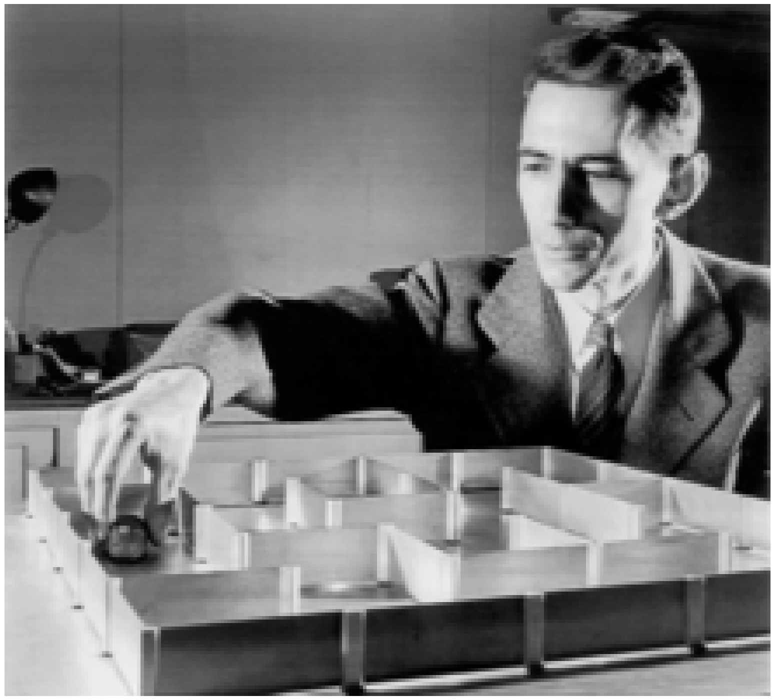
- Introduction Harold S. Black (1898–1983), invented the concept of negative feedback amplifiers in 1927. He managed to develop stable negative feedback amplifiers in the 1930s.

Hendrik Wade Bode

- Bode 

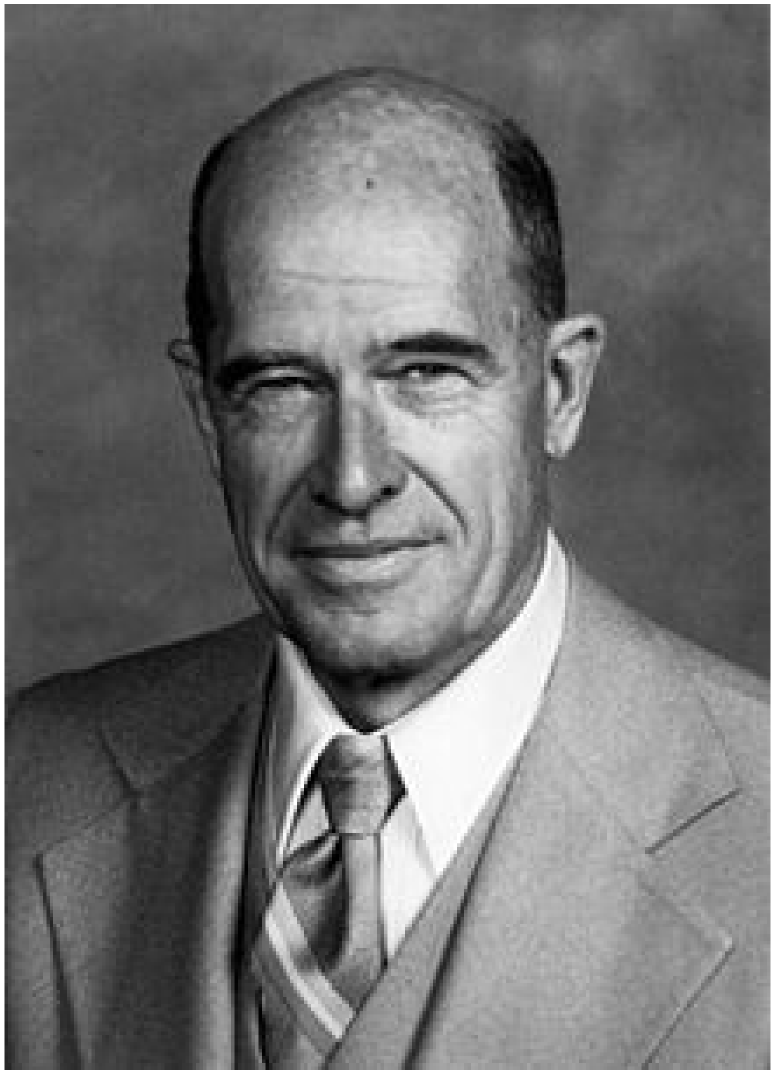
- Introduction Hendrik Wade Bode (pronounced Boh-dee in English, Boh-dah in Dutch),(24 December 1905 – 21 June 1982) was an American engineer, researcher, inventor, author and scientist, of Dutch ancestry. He made important contributions to control system theory and mathematical tools for the analysis of stability of linear systems, inventing Bode plots, gain margin and phase margin.

Claude Elwood Shannon

- Shannon 

- Introduction Claude Elwood Shannon (April 30, 1916 – February 24, 2001) is also credited with the introduction of sampling theory, which is concerned with representing a continuous-time signal from a (uniform) discrete set of samples.

Walter Richard Evans

- Evans 
- Introduction Walter Richard Evans (January 15, 1920 - July 10, 1999) was a noted American control theorist and the inventor of the root locus method in 1948.

Samuel Jefferson Mason

Samuel Jefferson Mason (1921–1974) was an American electronics engineer. Mason's invariant and Mason's rule are named after him.

describing function (DF) method

In control systems theory, the describing function (DF) method, developed by Nikolay Mitrofanovich Krylov and Nikolay Bogoliubov in the 1930s, and extended by Ralph Kochenburger is an approximate procedure for analyzing certain nonlinear control problems.

1.3 课程学习

自动控制

无人工直接参与的情况下，利用控制装置 (控制器) 使被控对象按照给定的规律变化。

自动控制理论

- 经典控制理论
- 现代控制理论

课程内容：

1. 一般概念
2. 数学模型
3. 分析方法
   (a) 时域分析法
   (b) 根轨迹法
   (c) 频域分析法
4. 控制器设计方法
5. 离散系统分析
6. 典型非线性系统的分析

2 反馈与控制

2.1 开环控制

开环控制

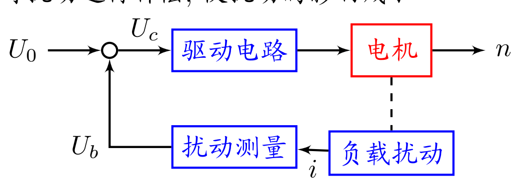
- 定义：开环控制是指控制器与被控对象之间只有顺向作用而没有反向联系，称为开环控制。
- 系统的输出量对系统的输入量无影响
- 开环系统对控制偏差无修正能力。
  - 按给定量控制
  - 按扰动量控制

按给定量控制

- 输入量: 电压 U_g
- 输出量: 电机转速 n
- $n = kU_g$

按扰动量控制

对扰动进行补偿, 使扰动的影响减小



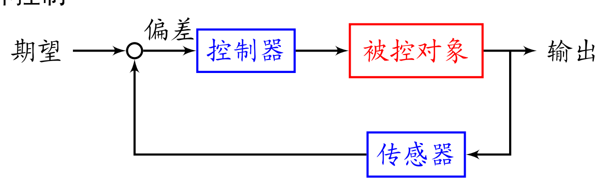
- $U_c = U_0 + U_b$
- 负载增加导致 $n\downarrow, i\uparrow$
- $i\uparrow\rightarrow U_b\uparrow\rightarrow U_c\uparrow\rightarrow n\uparrow$

开环控制特点

1. 优点：原理简单, 结构简单, 反应速度快, 灵敏度高
2. 缺点：
   - 对控制偏差无修正能力
   - 控制精度取决于各控制元器件的精度
3. 适应场合：对控制精度要求不高的系统
4. 结构图：输入 $\rightarrow$ 控制器 $\rightarrow$ 被控对象 $\rightarrow$ 输出（顺向作用）

2.2 闭环控制

闭环控制

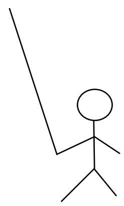
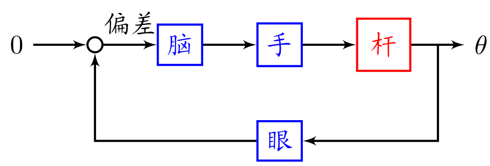


- 定义：闭环控制是指在输出量处, 通过 **反馈**回路使得输出量对输入量施加影响
- 控制目的：通过在输入端引入输出量, 使得输入处的偏差 $\rightarrow 0$
- 闭环控制按偏差进行调节。

反馈

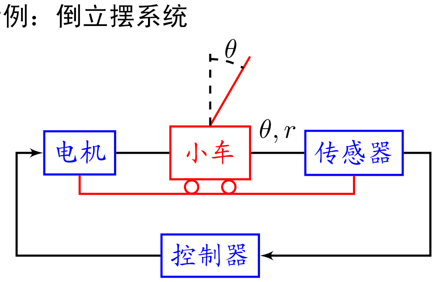
- 反馈: 指将系统的输出返回到输入端并以某种方式改变输入，进而影响系统功能的过程。
- 正反馈: 输出变化时, 反馈对输出造成的影响与输出变化趋势相同
- 负反馈：输出变化时, 反馈对输出造成的影响与输出变化趋势相反

示例：人手工竖杆

- 示意图 
- 分析 

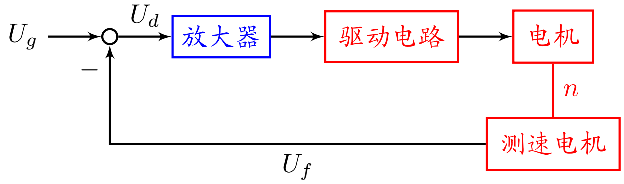
  - 反馈通道：眼
  - 执行机构：手
  - 被控制量：杆与竖直方向夹角 $\theta \to 0$

示例：倒立摆系统



- 执行机构：电机
- 反馈通道：角度传感器、位置传感器
- 被控制量：$\theta \to 0, r \to 0$

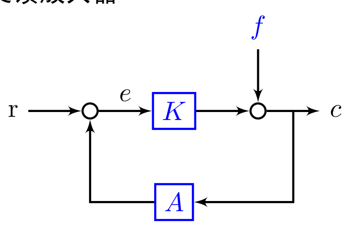
示例：直流电机速度反馈控制系统



$$n = KU_d \tag{1}$$
$$U_d = U_g - U_f \tag{2}$$
$$U_f = K'n \tag{3}$$

负载增大后: $n \downarrow \rightarrow U_f \downarrow \rightarrow U_d \uparrow \rightarrow n \uparrow$

负反馈放大器



$$c = Ke + f \tag{4}$$
$$e = r - Ac \tag{5}$$
$$c = \frac{Kc}{1+KA} + \frac{f}{1+KA} \tag{6}$$

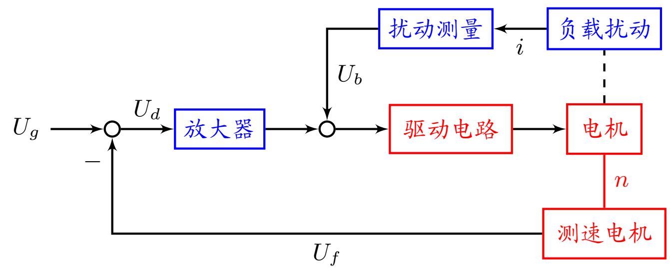
闭环控制的特点

1. 按偏差进行调节
2. 控制精度较高，取决于反馈通道元器件的精度，而反馈通道所包围的电路中的元器件的元件精度可降低
3. 抗干扰能力强

复合控制

扰动补偿 + 闭环控制

例：直流电机速度复合控制



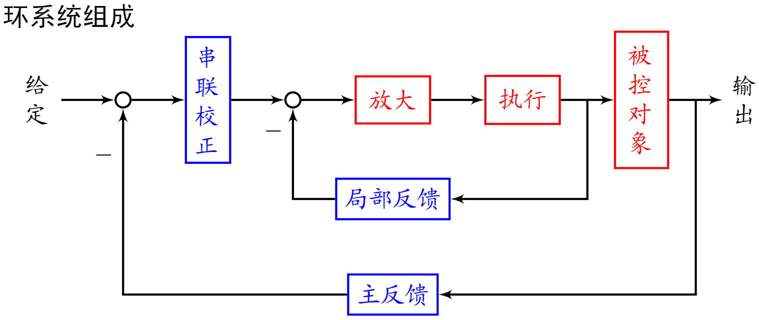
3 信号与系统

3.1 概念与分类

基本概念

- 信号: 随时间和空间变化的某种物理量.
  - 信号通常是时间变量 t 的函数
  - 信号的特性可从两方面来描述
    * 时域特性
    * 频域特性
- 系统: 能够对信号完成某种变换或运算功能的集合体称为系统

闭环系统组成



闭环系统中的信号

- 输入信号：给定信号及干扰信号
- 输出信号：被控量的物理量
- 反馈信号：反馈元部件的输出
- 误差信号：输出量的希望值与实际值之差
- 干扰信号：系统受到的内外干扰

典型信号

- 阶跃信号（函数）$r(t) = \begin{cases} A & t \geq 0 \\ 0 & t < 0 \end{cases}$
- 脉冲信号（函数）$r(t) = \begin{cases} \frac{A}{\epsilon} & 0 \leq t \leq \epsilon \\ 0 & others \end{cases}$
- 正弦信号（函数）$r(t) = A\sin(\omega t), t > 0$
- 斜坡信号（函数）$r(t) = Vt, t > 0$
- 加速度信号（函数）$r(t) = \frac{1}{2}at^2, t > 0$

按给定量的运动规律分类

1. 镇定系统：输入 $r(t)$ 不变
2. 程序控制系统：输入 $r(t)$ 按规律变化
3. 随动系统: 输入 $r(t)$ 随机变化

按系统性能分类

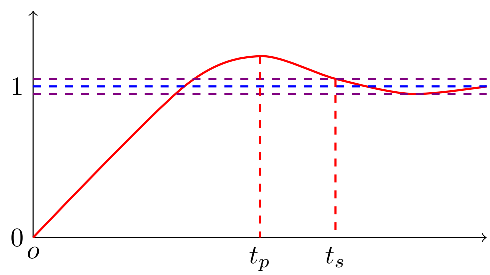
1. 线性系统和非线性系统
   - 线性系统: 系统的输入和输出因果关系可以用线性微分方程描述
   - 非线性系统: $r(t)$ 和 $c(t)$ 关系只能用非线性方程描述
2. 定常系统与时变系统
   - 定常系统：微分方程中各项系数为常数 $a_0c''(t) + a_1c'(t) = r(t)$
   - 时变系统: 各项系数中有随时间变化的量 $a_0(t)c''(t)+a_1(t)c'(t) = r(t)$
3. 连续系统与离散系统
   - 连续系统：系统中信号是时间 t 的连续函数的模拟量
   - 离散系统：系统中存在脉冲量或数字信号
4. 确定性和不确定性系统
   - 确定性系统：系统中微分方程参数变化是精确可知的
   - 不确定性系统：参数变化只是部分可知或近似可知

3.2 控制系统基本要求

基本要求：稳定性、稳态性能、瞬态性能

1. 稳定性: 正常工作的先决条件
2. 稳态性能: 指标：稳态误差
3. 瞬态性能:
   (a) 峰值时间：t_p
   (b) 调节时间：t_s
   (c) 超调量：$\sigma\% = \frac{c(t_p)-c(\infty)}{c(\infty)}$

示例: 响应曲线



- 初始值:0，期望值 1：
- 指标：
  - 超调量 $\sigma\%$
  - 调节时间 t_s
  - 上升时间 t_r
  - 峰值时间 t_p

指标

- 超调量：$(c(t_p) - c(\infty))/c(\infty)$
- 调节时间：若有 t_s，当 $t \geq t_s$ 时有 $|c(t) - c(\infty)| \leq 0.05c(\infty)$（或 $0.03c(\infty)$）成立，则 t_s 为该系统调节时间。
- 上升时间 t_r，定义
  - 100% 的 t_r $c(t)$ 首次达到 $c(\infty)$ 的时间
  - 90% 的 t_r $c(t)$ 首次达到 $90\%c(\infty)$ 的时间
  - 70% 的 t_r $c(t)$ 首次达到 $70\%c(\infty)$ 的时间
- 峰值时间 t_p ：$c(t_p) = Max(c(t))$