PID control: the early years

Aidan O’Dwyer

Technological University Dublin, aidan.odwyer@tudublin.ie

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Recommended Citation

O’Dwyer, Aidan :PID control: the early years. Control in the IT Sector Seminar, Cork Institute of Technology, Cork, May. doi:10.21427/q287-3p17

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PID control: the early years

Aidan O’Dwyer

“…if every instrument could accomplish its own work, obeying and anticipating the will of others … if the shuttle would weave and the pick touch the lyre without a hand to guide them, chief workmen would not need servants, nor masters slaves.”

Aristotle, Politics, Book 1, Chapter 3
[as quoted by Bennett (1979), preface to “A history of control engineering” 1800-1930, IEE Series 8]

This presentation will outline:
• Controller developments 1788 – c.1900
• 1900-1950: The role of instrument companies
• Early theoretical description of the PID controller
• Early tuning of the PID controller
• Some further developments since 1950
• Some conclusions
Controller developments: 1788 - c. 1900

1788: James Watt equips his steam engine with a flyball governor, the first mechanical feedback device with P control. See a video of the governor in action at http://www.geocities.com/Athens/Acropolis/6914/mpg.htm

1 http://www.btinternet.com/~historical.engines/Lap_engine.htm
2 http://www.tiscali.co.uk/reference/encyclopaedia/hutchinson/m0015351.html
Some further early developments

1791: G.R. de Prony: Developed governor with integral control action.

1857: H.N. Throop: Developed governor with proportional plus derivative control action.

1868: James Clerk Maxwell (1831-1879): He
- linearised the differential equations of the governed steam engine about an equilibrium
- showed that the closed loop system is stable if the poles have negative real parts
- showed that, if the governor was implemented with proportional control action, a large steady state offset resulted
- showed that this offset could be eliminated by introducing an integral control term
- showed that the system was unstable if the gain of the proportional controller was too high.

1911: Elmer Sperry: First PID controller – used to automate a ships steering mechanism. Elmer was the father of Laurence Sperry (1893-1924), who, in 1914, demonstrated the use of a gyroscope and ailerons to allow an aircraft to maintain level position under disturbances:
1900-1950: The role of instrument companies

Instrument companies produced automatic controllers for the process and manufacturing industries: metals, pulp and paper, lumber, power generation, chemicals, food, distillation and many more.

On-off controllers

1907: C.J. Tagliabue Co: First installation of a pneumatic automatic (on-off) temperature controller, New York

1910-: Development of on-off electrical and pneumatic controllers

1912: First on-off controller with a calibrated set-point scale (Foxboro)

1927: Pneumatic “narrow band” proportional controller – Foxboro

1925-1935: 75000 automatic controllers sold in the USA

Early automatic controllers were of three types:

a. Electrical relay with a solenoid operated valve – on-off
b. Electrical relay with motor operated valve – floating (integral) control
c. Pneumatic relay with a diaphragm valve (P action 1% - 5% PB)

PI controllers

1920: Morris E. Leeds: First patent for a pneumatic PI controller

1931: Clesson E. Mason: First pneumatic PI controller with a “wide band” proportional controller – Foxboro Co. Stabilog Model 10; method based on a negative feedback pneumatic amplifier

1933: Taylor (now part of ABB) Dubl-response plus Fulscope (Model 56R Fulscope) (allowed variable P and I settings)

1934: Tagliabue Company Damplifier

1936: Bristol Ampliset Free-Vane
**PID controllers**

1939: Taylor Instruments Fulscope 100 [continuously variable P, I, D settings]; the first pneumatic controller with full PID control capabilities in a single unit.

1951: The Swartwout Company introduce their Autronic line, the first electronic controllers based on vacuum tube technology.
Early theoretical description of the PID controller

- **1922**: Nicolas Minorsky (1885-1970) – first theoretical paper on PID control, applied to the automatic steering of ships. ³
- **1933**: John J. Grebe, Dow Chemical Co. ⁴
- **1934**: A. Ivanoff, George Kent Company, England ⁵ ... stated that the “science of automatic regulation of temperature is at present in the anomalous position of having erected a vast practical edifice on negligible theoretical foundations”
- **1935**: S.D. Mitereff ⁶ first gave the time domain equations of controllers and characterised them as P, PI, PD etc.

Early tuning of the PID controller

- **1934**: Albert Callander, Imperial Chemical Industries (ICI), England. Callander published an internal ICI report, called “Preliminary notes in automatic control”, in which he gave charts to allow tuning of a PD controller for a process with a delay. In two subsequent papers in 1935/6 and 1937 ⁷, Callander and co-authors proposed charts to allow tuning of PI and PID controllers for a range of processes with a delay.

---

A representative result is as follows:

\[
\text{Ideal controller } G_i(s) = K_i \left(1 + \frac{1}{T_i s} + T_d s\right)
\]

<table>
<thead>
<tr>
<th>Rule</th>
<th>(K_c)</th>
<th>(T_i)</th>
<th>(T_d)</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Callender et al.</td>
<td>(\frac{1.066}{K_m \tau_m})</td>
<td>(1.418\tau_m)</td>
<td>(0.353\tau_m)</td>
<td>Decay ratio = 0.043; Period of decaying oscillation = (6.28\tau_m \cdot \frac{\tau_m}{T_m} = 0.3)</td>
</tr>
<tr>
<td>(1935/6)</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>(\frac{1.066}{K_m \tau_m})</td>
<td>(1.418\tau_m)</td>
<td>(0.47\tau_m)</td>
<td></td>
</tr>
</tbody>
</table>

I first became aware of Callander’s work in September 2004 and e-mailed ICI to find out more, as the 1937 paper stated that the original of the diagrams that are used in the paper, together with other diagrams and equations, "are deposited in the Central Filing Dept. of ICI (Alkali) Ltd., Northwich, and are available for consultation there during business hours".

I got a reply in November 2004 from a ex-ICI member of staff (John Wheeler), a historian in the heritage records section, stating: I have to say that you are incredibly lucky: partly to have found someone in ICI willing to look up the information you wanted and also to have asked before it is all destroyed .... At the end of this year about 90% of our reports will be on the way to the incinerator. I am working in a part time voluntary capacity trying to save some of the historical material.

John very kindly sent me Callander’s early reports at the end of November 2004. The 1934 report, to my knowledge, describes the first ever tuning rule for controllers, eight years before the publication of the much better known work of John Ziegler and Nathanial Nichols.
Ultimate cycle tuning (Ziegler and Nichols, 1942)

1. Place the controller in proportional mode only (i.e. set $T_i$ to a maximum and $T_d$ to a minimum).
2. Increase $K_c$ until the closed loop system output goes “marginally stable”; record $K_c$ (calling it $K_u$, the ultimate gain), and the ultimate period, $T_u$.

3. PI controller settings:

$$K_c = 0.45K_u \ (PB_c = 2.22PB_u \%), \ T_i = 0.83T_u$$

4. (Ideal) PID controller settings:

$$K_c = 0.6K_u \ (PB_c = 1.67PB_u \%), \ T_i = 0.5T_u, \ T_d = 0.125T_u$$
**Process reaction curve tuning** (Ziegler and Nichols, 1943)

Open loop method (for the nervous …..)

![Open Loop Test Results](source: Control Engineering)

Side benefit: Knowledge of process transfer function

\[
G_m(s) = \frac{K_m e^{-sT_m}}{1 + sT_m}
\]

PI controller settings:

\[
K_c = \frac{0.9 T_m}{K_m \tau_m} \quad (PB_c = \frac{111 K_m \tau_m}{T_m} \%), \quad T_i = 3.33 \tau_m
\]

PID controller settings:

\[
K_c \in \left[ \frac{1.2 T_m}{K_m \tau_m}, \frac{2 T_m}{K_m \tau_m} \right] \quad (PB_c \in \left[ \frac{50 K_m \tau_m}{T_m}, \frac{83 K_m \tau_m}{T_m} \right] \%)
\]

\[
T_i = 2 \tau_m, \quad T_d = 0.5 \tau_m
\]

Many variations of the formulae exist.
Some further developments since 1950

1959: Bailey Meter Co. (now part of ABB) introduces the first fully solid-state electronic controller.

1964: Taylor Instruments demonstrates its first single-loop digital controller.

1969: Honeywell introduces their Vutronik process controller line with the derivative action calculated from the negative of the process variable rather than directly from the error.

1975: Process Systems (now MICON Systems) introduce the P-200 controller, the first microprocessor-based PID controller.

1976: Rochester Instrument Systems (www.rochester.com) introduces Media, the first packaged digital implementation of PI and PID control.

Nowadays, commercial software products are available that know many of the tuning rules and the different PID architecture. Some products:

1. BESTtune (http://bestune.50megs.com)
2. Control Arts PID tuning (www.controlartsinc.com)
3. Control Loop Assistant (www.lambdacontrols.com)
4. Control Station (www.controlstation.com)
5. EnTech tuner module (www.entechcontrol.com)
6. ExperTune (www.expertune.com)
7. INTUNE (www.controlsoftinc.com)
8. pIDtune (www.pidtune.com)
9. Pitops (www.artcon.com)
10. Protuner (www.protuner.com)
11. TOPAS (www.act-control.com)
12. TuneWizard (www.tunewizard.com)
Some conclusions

Industrial needs drove development

The role of technology was critical – mechanical pneumatic, electrical.

Development of control algorithms

- on-off control
- wide band proportional control
- PI control
- PID control

Use of feedback in the instruments

Leadership moved from Europe to the USA