Process Control

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1. Introduction
2. Instruments and Companies
3. Controller Technology
4. Advances in Theory
5. Conclusions

Introduction

- Industrial needs
- The role of technology
- Sensing, actuation and control combined
- Mechanical, pneumatical, electrical
- Clever solutions
- How to amplify?
- Control algorithms
  - On-off control
  - Narrow band proportional control
  - Wide band proportional control
- Use of feedback in the instruments
- Leadership moved from Europe to USA

Instruments

- Process and manufacturing industries: metals, pulp and paper, lumber, power generation, petroleum, chemicals, paint and varnish, food, brewery and distillery, glass and cheramics
- Need for instrumentation
  - Sensing
  - Recording
  - Control
- Control wide spread in mid 1920s
- Fraction of cost 0.4% (1920) to 1.4% in 1935. One third for controllers in 1923.
- More than 600 instrument companies in USA by mid 1930
- Measurement technology
- Instrument companies
- Instrument engineers
- Organizations

The Instrument Companies 1

- C. William Siemens and E. Werner Siemens London 1844, the chronometric governor which had integral action.
- Brown Instrument Company founded in mid 1800. Edward Brown invented a pyrometer for measuring temperature. Acquired by Honeywell 1934
- Taylor Instruments, George Taylor and David Kendall 1851. Thermometers and barometers.
- William Fisher constant pressure pump governor 1880
- Fisher Governor Company 1888 Marshaltown. Merged with GEC to form FisherControls International, 19xx. Became Fisher-Rousemount in 1992.

The Instrument Companies 2

- Butz Thermo-Electric Regulator Co 1885 reorganized in 1893 by Sweatt to become Sweatt's Minneapolis Heat Regulator Co..
- Honeywell Heating Speciality Co. (Mark C. Honeywell). Hot water systems for homes. Merged with Sweatts company in 1913
- Bristol Company 1894. Temperature controller 1903.Improved pressure indicator and recorder. Industrial Instrument Co 1908 in Foxboro. Changed to Foxboro Co in 1914. First multiple pen recorder 1915.
- Compression Rheostat 1903 Lynde Bradley and Stanton Allen
- 1899 Morris Leeds Company, joined with theoretical physicist Northrup to form Leeds & Northrup 1899. Precision instruments for labs; galvanometers, resistance boxes, industrial instrumentation 1920

The Instrument Companies 3

- 1900 Tagliabue Co air-operated temperature controller
- 1903 Lynde Bradley and Stanton Allen formed Compression Rheostat Co, a forerunner of Allen-Bradley
- 1916 Bailey Meter Company, Erwin G. Bailey instruments for boiler operation
- George Kent, England boiler control
- Elliot Brothers, England boiler control
- Siemens, Germany boiler control
- Hagan Controls, supplier of boiler and combustion control, became Westinghouse Combustion Control and in 1990 Rosemount Control.
- 1937 Fisher & Porter, Philadelphia rotameters
- Much turbulence in 1980 and 1990.

The Swedish Scene

- Nordiska Armaturfabriken
- TA
- Källe Regulator
- Billman Regulator
- ASEA
- AGA
- Bofors
- SAAB
- Philips Industrielektronik
- ElektronLund - Satt

Billman Control

- 1929 Stig K. M. Billman matsers Thesis KTH: Thermal processes associated with tem[perature controllers.
- Worked at Birka Regulator AB
- Founded own company March 16, 1932 for constructing and selling oil burners
- Exerpt from material
  - 1932 The Birka Controller
  - 1934 The motorized valve
  - 1942 The variator feedforward
  - 1956 First electronic HVAC system
  - 1963 The Airtronic system combines pneumatic and electric systems
- New facilities in Flemingsberg Stockholm
- Acquired by Landis & Gyr

Källe Regulator

- Torsten Källe Billerud

Tour & Andersson

- 1875 A. H. Andersson & Co Christiania valves
- Tour Agenturer, Stockholm RVO valve cooperation with AHA
- 1952 First electronic controller TE1
- 1955 Motorized valve
- 1962 First transistorized controller TE5
- 1966 Incentive buys A. H. Andersson
- 1970 Incentive buys 75
- 1975 Acquires part of Carl Olin AB DDC-6
- 1975 Computerized system 6000
- 1977 Tour & Andersson (TA) formed
- 1984 TA SYSTEM 7 energy control and building management
- 1995 TA Hydronics and TA Control
- 1996 Head office moves to Malmö

Nordiska Armaturfabriken NAF

1915-1920

- 1919 Standard Oil of New Jersey established an R&D Department to apply chemical engineering to oil industry
- 1921 Union Carbide began cracking of natural gas
- Strong demand for instrumentation
- On-off controllers widely used
- Instrumentation began to be used for devices used to measure and control process variables
- Pneumatic controllers in panels
- Emergence of control rooms
- Use of automatic reset (integral action)
- Occasional use of derivative action
- Signal transmission in tube
- Fisher Governor Co built first test laboratory 1929

1930-1940

- Scientific papers appear
- Difficult problems: pH, delays
- Drastic growth of industry more than 600 control companies in the US.
- Seven companies dominated, Foxboro, Brown and Taylor
- 1931 Foxboro Stabilog, adjustable gain and integral action
- 1933 Taylor Mod 56R with adjustable gain
- Foxboro Mod 40 proportional and reset recorder. Flow control in petrochemicals
- 1935 Taylor Fulscope 56R with Pre-Act
- 1937 Leeds & Northrup equal percentage valve.
- 1937 Fisher & Porter rotameter.
- 1938 Electronic potentiometer by Honeywell
- 1939 Taylor Fulscope

1950

- 1952 Gas-liquid chromatography James and Martin awarded Nobel Prize
- 1953 Coriolis mass flowmeter
- 1954 Foxboro electromagnetic flow meter
- 1956 Rosemount Engineering Co
- 1957 Ultrasonic level meters
- 1958 Single loop electronic controller
- 1959 4-20 mA signal standard
- 1960 Beta and infrared gauges for papermachines
- 1965 Beckman Instruments gas chromatograph
- 1969 Vortex flow meter Yokogawa

The Early Controllers

- Sensing, actuation and control integrated in early controllers
- Devices that could amplify?
- Actuators were valve or electric motors
- On-off control
  - Oscillations wear and tear
  - Oscillations reduced effects of friction
  - Worked well for systems with large capacities
- Narrow band proportional control
- Use feedback to linearize gave wide band proportional control. Doc. C. E. Mason and Frymoyer at Foxboro, Stabilog 1931
- Modularize and structure systems and components
- Tinkering not theory based, considerable confusion

Derivative Action

- 1930 Leeds & Northrup anticipating controller
- 1931 Bristol company degree-splitting anticipation
- 1931 Ralph Clarridge at Taylor used pre-act
  - Manufacturing of viscose rayon
  - Large lags in thermocouple
  - Difficult to obtain high gain
  - Large off-sets
  - Integral action did not help
  - Very good results with pre-act
- 1939 Taylor Fulscope a PID controller

Quote from Interview with Ziegler

"Someone in the research department (Ralph Clarridge) was tinkering with Fulscopes and somehow had got a restriction in the feedback line to the capsule that made the follow-up in the bellows. He noted that this gave a 'kicking' action to the output. They tried this on the rayon shredders and it gave perfect control on the temperature. The action was dubbed 'Pre-Act' and was found to help the control in other difficult appliacations, like refinery stills. the Pre-Act was the first derivative control and was incorporated into the Model 56R."

Commentary

- Notice work by Stodola!

From Interview with Ziegler

"The Pre-Act was not too popular, but I insisted in getting a more stable version of it incorporated in the Fulscpoe 100. ... Bill Vogt designed the reproducible needle valves for setting reset rate and pre-act time. This was the very first proportional plus reset plus derivative control integrated in one unit.

What was the market reaction?: Enthusiastic as hell! We knocked our prime competitor right out of major chemical plants, such as Dow and Monsanto. They thought it was such a wonderful mechanism with responses labeled with calibrated units. ... It had

- Settings for sensitivity, reset and preact. (No other controller had this.
- Any combination, P, PI, PD, PID or on-off
- Calibrated dials
- Continuous wide ranges

I. M. Stein Leeds & Northrup

"The operator automatically observes not only the momentary condition and the direction of change of that condition, but observes also the rate of change of that condition with respect to time (the first derivative) and the rate of change of the rate of change (the second derivative). These observations are very essential to close regulation, particularly in processes involving appreciable time lag."

Commentary:

- Compare Smith predictor
- Importance of process input

The Soul of a Pneumatic Controller

- Flapper valve
  - 1885 Johnson, flapper nozzle
  - 1914 E. H. Bristol used it in controllers
- Pneumatic amplifier
- Bellows
- Volumes and restrictions
- Feedback makes a linear system of strongly nonlinear components
- Foxboro Stabilog Mason and Frymoyer
- The principle of force balance

The Components

The flapper valve

Volume with a restriction

The pneumatic amplifier

The Force Balance Principle

The proportional controller

PI and PID Controllers

PI control

PID control

Integration with Valves

The Soul of a Temperature Controller

- Use motor with relay as an amplifier
- Feedback linearizes the response
- Thermistors give long time constants

Controller with Thermal Feedback

Block diagram

How to obtain large time constants?

Process Control Theory

- Essential in Development of PID controller
- Little impact on engineering practice
- Difficulties
  - Industrial structure
  - Complex behavior, time delays,
  - Understanding process dynamics
- Simulation
- Actors
  - Callender and Stevenson ICI
  - Hartree and Porter U Manchester
  - Ivanoff Kent Instruments
  - Mason and Philbrick Foxboro
  - Bristol and Peters Leeds & Northrup
  - Ziegler and Nichols Taylor
  - Spitzglass Tagliabue
  - Grebe Dow
  - Mitereff
- Organization

Ivanoff

Theoretical foundations of automatic regulation of temperature. Institute of Fuel **7** (1934) 117-130.

Ivanoff 1933: "In spite of the wide and ever-increasing application of automatic supervision in engineering, the science of automatic regulation of temperature is at present in the anamolous position of having erected a vast practical edifice on negligible theoretical foundation."

- Used arguments based on frequency response to understand temperature control loops
- Primitive understanding of stability condition: loop gain less than one at ω_{180}
- Found that with proportional feedback loopgain must be less than 23.1. See Bennet page 51. Explain!

Mitereff

Principles underlying the rational solution of control problems. Trans ASME **57** (1935), 159-163.

"Automatic control problems are solved at present by purely empirical methods and after installation the ususal cut-ant-try method of adjustment is very tedious and unreliable."

Systematic characterization of controllers

1. $u = k \int edt$
2. $u = ke$
3. $u = k_1 e + k_2 \int edt$
4. $u + k_2 \frac{du}{dt} = k_1 e$
5. etc

Discussions of paper refered to Routh.

Simulation

- The Differential Analyzer
  - Lord Kelvin Ball and disk integrator
  - Hannibal Ford Integrator
  - The torque amplifier
  - 1930 Vannevar Bush MIT
- 1935 Callender Hartree and Porter: Time lag in control system. Phil. Trans. Roy. Soc. **235** (1935-36), 415-444

$$u = k_1 e + k_2 \int edt + k_3 \frac{de}{dt}$$

$$T\frac{d(t)}{dt} + e(t) = u(t - T)$$

- Mason and Philbrick at Foxboro
- Ziegler and Nichols: Optimum settings for automatic controllers. Trans ASME **64** (1942) 759-768.
- Little short term impact because differential analysers were not available
- Very large long term impact

Ziegler and Nichols

- Characterization of process dynamics
  - Reaction curve a and L
  - Frequency response K_u, t_u
- Dimension-free parameters
- Used simulation to find controller parameters
- Good packaging of results for practical use
- Integrated process and control design

John G. Ziegler on PID

I did not know how to set this new controller and I realized that we had to get some way of determining the controller settings rather than cut-and-try. I was out on a still in a chemical plant and it was almost a life's work getting the settings. I finally got it stable, but I was'nt sre I had the right setting. We had a unit in our factory demonstration room which consisted of a series of tanks and capillaries to simulate a multicapacity system for a fairly typical porcess to control pressure.

Quarter Amplitude Damping

Nick came to Taylor in the research department about the time the Model 100R was developed. I was playing on this analog simulator trying to figure out what determined the sensitivity, the reset rate and the pre-act time.

...

It turned out that when you set the proportional to about half of what caused the ultimate sensitivity, you would have about 25% amplitude ratio. So that is what we sait - get an ultimate sensitivity and note the period. Any moron can do that. Then set the reset rate at one over the period and set the pre-act time to 1/6 or 1/8 of the period.

...

Nick wanted to use a 37% decay for some mathematical reason, but I insisted on the 25 % because it was very easy for someone to see that the second wave is half as big as the first wave.

Use of Simulation

Nick was cranking lut these curves for me for a lot of different processes. ... To speed it up. Nicke rented the differential analyzer at MIT and got into discussions with people at MIT on fire control. They were having trouble keeping the systems stable, and Nick believed that even though their math was correct, there was another little time constant they were missing in the loop somewhere. He guessed it was the compressibility of the hydraulic fluid, which they denied. He convinced them to use Taylors pre-act, or derivative action, and when they put it in, the guns were stable.

As a result of all this, they asked him to come to the Radiation Lab at MIT to help win World War II. Taylor would not give him a leave of absense to he left.

Process and Control Design

The cronology in process design is evidently wrong. Nowadays an engineer first designs his equipment so that it will be capable of performing its intended funtion at the normal throughput rate ... The control engineer ... is then told to put on a controller capable of maintaining static equilibrium for which the apparatus was designed. ... When the plant is started, however, it may be belatedly discovered that ... the control results are not within the desired tolerance. A long expensive process of 'cut-ant-try' is then beguyn in order to make the equipment work ... [then it is realised that] some factor in the equipment design was neglected. ... The missing characteristic can be called 'controllability', the ability of the process to achieve and maintain the desired equilibrium value.

Organization

- Progress made by engineers in instrument companies. Little academic involvement
- Role of professional organizations
- The journal *Instruments*
- 1936 The Process Industries Division of ASME formed Industrial Instruments and Regulators Committee in 1936. Ed Smith of Tagliabue driving force. Unified terminology, exchange of ideas and experiences.
- 1942 AAAS chose Instrumentation as the topic for a Gibson Conference
- 1945 Institute of Measurement and Control, London
- 1946 ISA formed as an organization for instrument technicians, plant operators. Open to people who did not hav access to other professional societies.
- Instrumenttekniska föreningen, Stockholm

Computer Control

- Overview
- PLL
- System Structure
- From Hardware to Software

Overview

- 1956 TRW and Texacon
- March 12 1959 Port Arthur online, supervisory control 26 flows, 72 temperatures, 3 pressures, 3 compositions
- Supervisory Control
- 1962 DDC ICI Ferranti
- 1965 PDP-8
- Honeywell TDC 2000, Yokogawa Centum
- 1970 PLC
- ASEA Master 1980

Programmable Logic Controllers

- Two aspects of process automation
  - Instruments and relays
  - Instrument engineers and electircians
- Late 1960 General Motors specifications
- Digital PDP-14 at GM
- Ladder logic: Bedford Associates
- 1970 Modicon 084

ElektronLund

- Small group that made hardwired logic for industrial automation led by Homerberg in Lund. Göran Andersson Technical Director saw Digitals PDP14 at Volvo in Skövde and Alan Bradley system
- Reverse Engineering
- 1972 Masters thesis project by Göran Sigfridsson and Claes Alerup from LTH. Led to a product PBS (Programerbart Binärt System) in 1973
- 1976 Satt Elektronlund
- 1981 Satt Electronics Lund division grew larger than main branch
- 1982 Attempt of ABB takeover
- 1983 SattControl

Sampled Data Systems

- The sampling theorem Shannon Kotelnik
- Oldenburg and Sartorius 1948
- Columbia University
  - The Sage System
  - Jury Franklin
  - Tsypkin

Conclusions

- Major progress in technology
  - Sensors
  - Actuators
  - Controllers
  - Standardization
  - Mudularization
  - Nomenclature
- Embryo of theory
- The PID controller
- Use of feedback in instruments
- Simulation methods emerged
- Organization