控制回路的 PID 参数整定

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摘　要：PID 控制以其结构简单、稳定性好、工作可靠、调整方便而成为工业控制的主要技术之一。被控制对象的结构和参数会随着时间的推移而变化，根据被控制对象的实际情况，调整 PID 参数的设置可以保证最佳的控制效果。因此，掌握 PID 参数整定的基本方法具有重要意义。文章在分析了 PID 控制原理的基础上，分别对阶跃响应动态测试法、临界比例度法、经验试凑法等进行了详细探讨，比较了它们之间的特点。

关键词：控制回路；PID 控制；参数整定

中图分类号：TM571　　**文献标识码**：A　　**文章编号**：1001-2206（2007）06-0027-03

0　引言

在工程实践中，应用最为广泛的调节器控制方式为比例、积分、微分控制，简称 PID 控制，又称 PID 调节。它以结构简单、稳定性好、工作可靠、调整方便而成为工业控制的主要技术之一。当不完全了解一个系统和被控对象，或不能通过有效的测量手段来获得系统参数时，最适合用 PID 控制技术。PID 控制器根据系统的误差，利用比例、积分、微分计算出控制量进行控制。掌握 PID 参数整定的基本方法具有重要意义。

1　基本原理

1.1　比例控制器（P）

比例控制器的传递函数为：

$$Gc(S)=K_p$$

式中　S——频域变量；

K_p——常数。

比例控制器的作用是调整系统的开环比例系数，提高系统的静态精度，加快系统的响应速度，但对于高于二阶的系统，K_p 过大会造成系统的不稳定。

1.2　积分控制器（I）

积分控制器的传递函数为：

$$Gc(S)=1/T_iS$$

式中　T_i——积分时间。

积分控制器的作用是消除系统的静态误差，但它有时会改变系统的稳定性，降低系统响应速度。

1.3　比例加积分控制器（PI）

比例加积分控制器的传递函数为：

$$Gc(S)=K_p(1+1/T_iS)$$

由于它有 K_p 和 T_i 两个可调参数，因此可兼有比例和积分两种控制器的优点，使系统既稳定又有较好的静态和动态性能，这种控制在工程上用途最广泛。

1.4　比例加微分控制器（PD）

比例加微分控制器的传递函数为：

$$Gc(S)=K_p(1+T_dS)$$

式中　T_d——微分时间。

它所产生的控制作用不仅反映了系统的静态误差，同时还反映了误差信号的变化率，因此微分使控制信号提前作用，使系统的响应振荡减轻，过渡过程加快，对系统的稳定性有利。

1.5　比例加积分加微分控制器（PID）

PID 控制器的传递函数为：

$$Gc(S)=K_p(1+1/T_iS+T_dS)$$

PID 控制器兼具比例积分和微分控制器的优点，是应用很普遍的一种控制器。

2　控制器的参数整定

控制器的参数整定方法很多，下面针对不同的

控制回路，介绍几种动态测试法和工程上常用的简便经验方法，供选择应用。

2.1 阶跃响应动态测试法

该方法首先根据不同系统选择相应的公式，然后利用阶跃响应测试测出有关的动态参数，根据不同的公式计算控制器的参数，最后对计算出来的参数做适当的调整，直至获得满意的动态响应曲线。

2.1.1 单回路控制器控制参数的整定

2.1.1.1 流量控制器

控制回路置手动，改变阀门开度 ΔOP，得到响应曲线如图 1 所示。

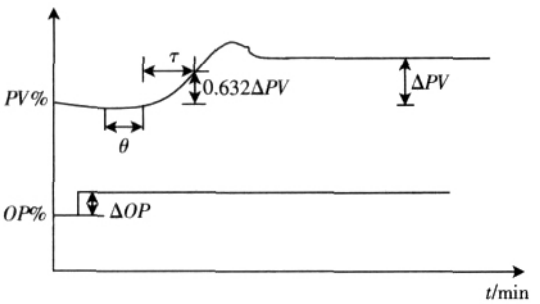

图 1 单回路流量、温度控制器的响应曲线

过程增益 $K_p = \Delta PV/\Delta OP$

式中 ΔPV——输出稳态偏差；

ΔOP——输入偏差。

流量控制一般采用 PI 控制器，K_c 与 T_i 由以下经验公式求得：

$$K_c = \frac{1}{K_p} \times \frac{\theta + 2\tau}{2\theta + 3\tau}$$

$$T_i = \theta + 0.5\tau$$

式中 K_c——控制器参数中的比例增益；

θ——过程对象的纯滞后响应时间；

τ——过程对象的输出在第一次达到稳态偏差的 0.632 倍时所经历的时间。

如果采用比例带，则 $P_B = 100/K_c$

式中 P_B——控制器参数中的比例带。

2.1.1.2 温度控制器

控制回路置手动，改变阀门开度 ΔOP，得到响应曲线如图 1 所示。

过程增益 $K_p = \Delta PV/\Delta OP$

温度控制一般采用 PID 控制器，K_c、T_i、T_d 由以下经验公式求得：

$$K_c = \frac{1}{K_p} \times \left(\frac{4\tau}{3\theta} + \frac{1}{4}\right)$$

$$T_i = \frac{32\tau + 6\theta}{13\tau + 8\theta} \times \theta$$

$$T_d = (0.25 \sim 0.33)\, T_i$$

2.1.1.3 液位控制器

控制回路置手动，改变阀门开度 ΔOP，得到响应曲线如图 2 所示。

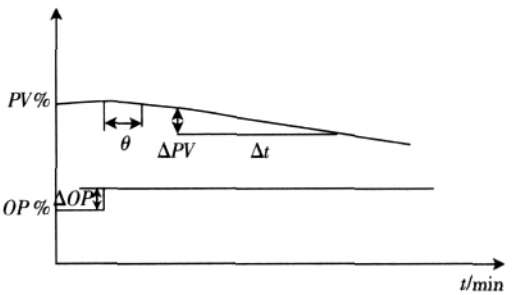

图 2 单回路液位控制器的响应曲线

过程增益 $K_p = (\Delta PV/\Delta t)/\Delta OP$

式中 Δt——衰减所经历的时间。

液位控制一般采用 PI 控制器，K_c 与 T_i 由以下经验公式求得：

$$K_c = \frac{1}{K_p} \times \frac{\theta + 1}{2\theta + 1} \times K_v$$

式中 K_v——速度系数（< 0.5）。

T_i = 10 min（快速调节）

T_i = 40 min（缓慢调节）

T_i = 20 min（平均速度调节）

2.1.1.4 压力控制器

控制回路置手动，改变阀门开度 ΔOP，得到如图 2 所示的响应曲线。

过程增益 $K_p = (\Delta PV/\Delta t)/\Delta OP$

压力控制一般采用 PI 控制器，K_c 与 T_i 由以下经验公式求得：

$$K_c = \frac{1}{K_p} \times \frac{\theta + 1}{2\theta + 1} \times K_v$$

式中 K_v——速度系数（0.5 ~ 0.8）。

T_i = 10 min（快速调节）

T_i = 40 min（缓慢调节）

T_i = 20 min（平均速度调节）

2.1.2 串级调节控制器的参数整定

先整定副回路，后整定主回路，在整定副回路时，主回路置手动。单独主副回路的整定方法同前，但需要特别注意的是主回路的积分时间至少应是副回路的 3 ~ 5 倍。

2.2 其他整定方法

2.2.1 临界比例度法

令 $T_i \to \infty$（一般取 100 ~ 200 min 即可），$T_d = 0$，此时控制器为纯比例控制器，通过调整控制器的比例系数 K_c，做阶跃响应测试，使 PV 曲线出现如图 3 所示的图形。

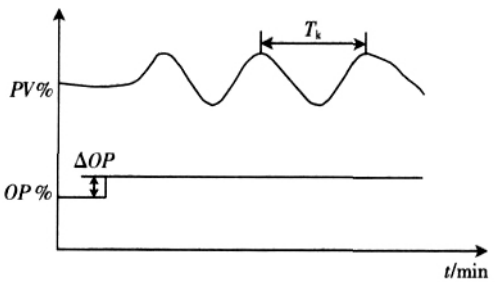

图 3　临界比例度法的响应曲线

不同控制规律的参数可由表 1 中的经验公式得到。

表 1　不同控制规律的经验参数

控制规律	K_c	T_i / min	T_d / min
P	0.5 K_p		
P+I	0.454 5 K_p	0.85 T_k	
P+D	0.555 6 K_p		0.1 T_k
P+I+D	0.588 K_p	0.5 T_k	0.125 T_k

注：T_k 为振荡周期

2.2.2　经验凑试法

经验试凑法就是针对具体的控制回路，根据给定的参数范围微调参数，直到得到满意的控制效果。不同控制系统的经验凑试参数可根据表 2 得到。

表 2　不同控制系统的经验参数

控制系统	K_c	T_i / min	T_d / min
温度	5 ~ 1.67	3 ~ 10	0.5 ~ 3
流量	2.5 ~ 1	0.1 ~ 1	
压力	3.33 ~ 1.43	0.4 ~ 3	
液位	5 ~ 1.25	1 ~ 5	

3　结束语

PID 控制器的参数整定是控制系统设计的核心内容，它是根据被控过程的特性确定 PID 控制器的比例系数、积分时间和微分时间的大小。PID 控制器参数整定的方法很多，概括起来有两大类：一是理论计算整定法，主要是依据系统的数学模型，经过理论计算确定控制器参数。这种方法所得到的计算数据未必可以直接应用，还必须通过工程实际进行调整和修改。二是工程整定方法，主要依赖工程经验，直接在控制系统的试验中进行参数整定，其方法简单、易于掌握，在工程实际中被广泛采用。

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收稿日期：2007-05-10；修回日期：2007-10-30

信息综括

九江石化电修车间修旧利废节能降耗见成效

为了降低检修能耗和维护成本，九江石化建安公司电修车间工会积极开展节能降耗班组小指标劳动竞赛，建立健全车间和班组成本核算台账及检修原材料消耗台账，将电气易耗材料分别建档，把检修可控费用指标细化、量化到个人，每月进行考核评比。

该车间实行以修代换、以旧代新的节能降耗新举措，努力降低检修能耗和物耗。做到能够修理的电气设备坚决不更换新的，对检修更换下来的开关、接触器、继电器、电机轴承、废旧电缆等旧件及时进行综合回收利用，将电气元件未损坏部分进行拼装，在确保能够满足设备安全运行的前提下，以旧代新，再次投入使用。班组修理了大量的报废电机，利用废旧电缆制作检修临时照明灯具引出线。维护班还自制了废油回收桶，把检修用过的污油经过过滤、沉淀后再次利用，全年车间能够节约煤油 20 多吨，计 6 万多元，有效地降低了检修能耗和成本。

修旧利废不仅使电修车间职工在工作中养成了勤俭节约的好作风，而且可以挖潜增效。据不完全统计，仅去年该车间修旧利废节约检修经费超过 30 万元。由于双增双节成绩突出，九江石化电修车间化肥维护班被江西省总工会评为“双增双节竞赛”全省先进班组，连续 5 年被评为九江市“双争立功竞赛”先进班组。

江西省九江石化总厂建安公司　汪学峰　收稿日期：2007-09-01

XU Feng-chi, et al.

Abstract: The characteristics of interface interaction between geosynthetics and soil are the key factor for geosynthetics reinforcement engineering. Hence it is essential to quantify the interaction by pulling out tests. This paper presents the results of pulling out tests using three kinds of native geosynthetics as reinforcement materials; and using sand, rock chips and silty clay as filling materials respectively. The comparisons are made under different conditions including soil filling quality, soil filling compactness, vertical pressure and geosynthetics surface roughness. Some useful conclusions are obtained on the basis of the results.

Key words: geosynthetics; reinforcement soil; pulling out test; interface interaction characteristics

· ENGINEERING DESIGN ·

(16) Setup of Compressor Stations of West to East Gas Pipeline for Increasing Gas Transportation Capacity

LIN Bo-cheng (Gansu Management Division of West to East Gas Pipeline, Wuwei 733000, China), ZHOU Xue-shen

Abstract: West to East Gas Pipeline is the largest gas transmission pipeline in China featuring the longest distance, highest pressure and maximum gas transportation capacity. The original designed gas transportation capacity is 120×10^8 m^3/a and has 10 gas compressor stations along the pipeline. According to the downstream market situation, the gas transportation capacity of West to East Gas Pipeline will be increased by 50×10^8 m^3/a and the whole gas transportation capacity will reach 170×10^8 m^3/a in 2007. The compressor stations will be increased by 12 and the whole compressor stations will reach 22. This paper presents the setup of new compressor stations of West to East Gas Pipeline, their driving mode selections, machine unit deployment, hydraulic calculations, etc.

Key words: West to East Gas Pipeline; compressor station; increasing transportation capacity; machine unit; hydraulic calculation

(20) Safety Correlation System Design of Petroleum and Petrochemical Equipment

LIU Chao-ming (China Natural Gas and Petroleum Operation and Development Corporation, Beijing 100034, China)

Abstract: Based on the design and operation experience of the safety correlation system of Fula Oilfield Development Project in Sudan, this paper introduces comprehensively the design principle, design procedure, design method as well as relevant nomenclatures and concepts regarding safety correlation system. The design principle mainly relates to validity, reliability, safety integrality distribution, objective failure, synthesis of validity and reliability as well as economy and applicability. The design program involves the objects of the safety system in every part and every phase of design life period. The design methods mainly refer to system design and system configuration. These provide the program and method used for reference for similar systems.

Key words: safety correlation system; safety integration; safety life period; validity; reliability

· CONSTRUCTION & INSTALLATION ·

(25) Cleaning and Keeping Clean Techniques for Process Pipeline at Large Scale Compressor Station

WANG yan (Beijing University of Chemical Engineering, Beijing 100029, China), ZHANG Ji-kai, ZHU Huai-de, et al.

Abstract: The process pipeline in compressor zone of Jiuquan Compressor Station has miscellaneous materials and many different pipe diameters. The quality of cleaning and keeping clean is very important to lubricating oil washing of Italian compressor system and quality and time period of overall compressor construction. CPP No.2 Engineering Company adopted careful and strict pipeline cleaning techniques such as dustproof, sundries cleaning up, welding slag eliminating in this pipeline project and created the optimum construction quality and the shortest construction period of domestic large scale compressor stations. This paper describes concrete approaches of cleaning and keeping clean for process pipelines at large scale compressor stations.

Key words: compressor station; process pipeline; cleaning and keeping clean; quality; time limit of project

(27) PID Parameter Tuning of Control Loop

XIAO-Xia (CNPC No.6 Construction Company, Guilin 541004, China), WANG Xue-mei

Abstract: PID control has become one of main techniques of industry control because of its simple

structure, good stability, reliable operation and facile adjustment. The construction and parameters of controlled object change with time elapsing; PID parameters need adjusting according to the actual state of the controlled object so as to guarantee the optimal control effect. Therefore, mastering basic PID parameter tuning method is significant. This paper analyses PID control principle, discusses respectively in detail the step response dynamic test method, critical proportionality method and empirical trial method. It also compares their features.

Key words: control loop; PID control; parameter; tuning

(30) Foundation Treatment of Zhuhai Natural Gas Land Terminal with Vacuum-Surcharge Preloading Method

ZHANG Xin-zhou (CNPC No.1 Construction Company, Luoyang 471023, China), REN Lan-you, SONG Shu-ling

Abstract: Commonly used methods for soft foundation treatment, such as piling and heavy tamping, have the disadvantage of high treatment cost. Zhuhai Natural Gas Land Terminal adopted vacuum-surcharge preloading method to treat foundations. It reduced cost and gained evident effects. Based on the geological conditions of the project, the design loads and preloads, performance requirement and deployment spaces of plastic drainage plates were calculated. The whole construction process and test methods were presented. The treated foundation bearing capacity increased from 45 kPa to 150 kPa and met design requirement.

Key words: ultra-soft foundation; vacuum-surcharge preloading method; settlement; consolidation

(33) Quality Control of Impermeable Concrete in Engineering Application

CONG Xin-he (Kelamayi Petrochemical Supervision Company, Kelamayi 834003, China), WANG Wei-dong, WANG Zong-chang

Abstract: Waterproof and impermeable abilities are very important to keep the normal state of an engineering project, and the key method to increase impermeability is to use impermeable concrete. Combined with the construction practice of large scale industrial water storage pools and recirculated cooling systems in Kalamayi region, this paper expatiate on the quality control links and applied effects in impermeable concrete application with respect to selection of raw and processed materials, design of proportional ratio as well as main performances and specifications of the concrete. The detailed and actual data presented in this paper will offer the direct reference and applicative value for craft brothers.

Key words: impermeable concrete; raw and processed materials; selection; design of proportional ratio; impermeability

· ANTICORROSION & THERMAL INSULATION ·

(37) Applying Liquid Coatings for 3PE Pipeline Field Joints

SHI Hang(China Petroleum Pipeline Engineering Corporation, Langfang 065000, China), REN Li-yuan, LIANG Qiang

Abstract: In the gas transportation pipeline construction at Guandong LNG Station, the technique of using liquid epoxy for 3PE anticorrosion pipeline field joints was applied for trial for the first time in our country. Based on the study of mechanism and related field construction technical standard, the characteristics of this new field joint technique are summarized, which include simple coating process, strong interface binding force, easy mend method, reliable inspecting results, lower material price, lower energy consumption, faster flow operation and without cathodic protection shielding. In order to improve this new field joint technique, the primary technical standard is established.

Key words: pipeline; polyethylene anticorrosion layer; liquid epoxy; anticorrosion; field joint

(40) 3PE Anticorrosion Technique of Heating Bending Pipes

ZHOU Jian-qin(Sichuang Petroleum Construction Company, Ltd., Chengdu 610213, China), HE Rui

Abstract: Anticorrosion of heating bend pipes is a problem all along in buried pipeline construction. It affects directly the service life of the pipeline. Although 3PE anticorrosion layer with excellent anticorrosion performance is widely used in straight pipes, 3PE anticorrosion layer used for heating bend pipes is still absent at home and abroad. In this paper, the research on 3PE anticorrosion layer used for heating bend pipes is described. The anticorrosion layer consists of an epoxy powder primer, a polymer glue intermediate layer and a polyethylene surface layer. Polymer glue and polyethylene are formed a composite PE tape of certain width and thickness at workshop, then it is sent to an anticorrosion production line to perform anticorrosion